



National Defence
Research and
Development Branch

Défense nationale
Bureau de recherche
et développement

TECHNICAL MEMORANDUM 97/207
January 1997

ADDED RESISTANCE PREDICTION IN
SHIPMO7 USING A NEAR-FIELD METHOD

Kevin A. McTaggart

DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

DTIC QUALITY INSPECTED 4

Defence
Research
Establishment
Atlantic



Centre de
Recherches pour la
Défense
Atlantique

Canada

19970728 176

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

9 GROVE STREET

P.O. BOX 1012
DARTMOUTH, N.S.
B2Y 3Z7

TELEPHONE
(902) 426-3100

CENTRE DE RECHERCHES POUR LA DÉFENSE ATLANTIQUE

9 GROVE STREET

C.P. BOX 1012
DARTMOUTH, N.É.
B2Y 3Z7



National Defence
Research and
Development Branch

Défense nationale
Bureau de recherche
et développement

ADDED RESISTANCE PREDICTION IN SHIPMO7 USING A NEAR-FIELD METHOD

Kevin A. McTaggart

January 1997

Approved by R.W. Graham:
Head/Hydronautics Section

TECHNICAL MEMORANDUM 97/207

**Defence
Research
Establishment
Atlantic**



**Centre de
Recherches pour la
Défense
Atlantique**

Canada

Abstract

This technical memorandum discusses the implementation of a near-field method for prediction of added resistance in the strip theory program SHIPMO7. Comparisons with experimental data for Series 60 hull forms and a frigate indicate accuracy similar to other methods, including three-dimensional codes. Advantages of the current method include computational efficiency, robustness, and reasonable values for added resistance in following seas. Inclusion of the SHIPMO7 dynamic swell-up option improves accuracy of added resistance predictions for the frigate but degrades accuracy for the Series 60 hull forms.

Résumé

Cette note technique traite de la mise en oeuvre d'une méthode de prévision par champ proche de la résistance accrue dans le programme SHIPMO7 de la théorie des bandes. Les comparaisons avec les données expérimentales pour les formes de coque de la série 60 et une frégate indiquent que la précision est similaire à celle des autres méthodes, y compris les codes tridimensionnels. Les avantages de la méthode actuelle sont l'efficacité de calcul, la robustesse et des valeurs raisonnables de la résistance accrue dans des mers arrière. L'utilisation de l'option de correction de la houle SHIPMO7 semble améliorer les résultats pour la frégate mais semble empirer les résultats pour les formes de coque de la série 60.

DREA TM/97/207

ADDED RESISTANCE PREDICTION IN SHIPMO7
USING A NEAR-FIELD METHOD

by

Kevin McTaggart

EXECUTIVE SUMMARY

Introduction

The resistance of a ship travelling through waves is known to be greater than the ship resistance in calm water. This resistance due to waves, commonly called added resistance, arises from the temporal average of the unsteady surge force acting on the ship. Added resistance is important in ship design because it can increase propulsion requirements for a ship which must achieve a specified speed in a seaway. The increased propeller speed required to overcome added resistance will also reduce the cavitation inception speed for a ship. This report describes the implementation of an added resistance prediction capability into DREA's strip theory ship motion program SHIPMO7.

Principal Results

The new added resistance method uses short and long wavelength approximations to predict added resistance over the entire wavelength range. Comparisons with model tests for Series 60 ships in head seas and an *FFG 7* in head and oblique seas indicate that SHIPMO7 gives fair agreement, which is consistent with other prediction methods, including more complex three-dimensional codes. In general, added resistance is more difficult to predict than ship motions because added resistance is a second-order phenomenon. In following seas, SHIPMO7 gives significantly better added resistance predictions than some of the other methods. The SHIPMO7 dynamic swell-up option influences added resistance predictions, giving better agreement with experiments for the *FFG 7* in head seas and worse agreement for the less slender Series 60 ships.

Significance of Results

SHIPMO7 now has a robust, computationally efficient method for predicting added resistance in waves. It is uncertain whether three-dimensional methods provide superior results to strip theory which would warrant their usage. Although the present method is limited in accuracy, it can be used for approximate estimates which can be useful in preliminary design work.

Future Plans

The present method likely represents the limit for accuracy of added resistance predictions using strip theory. Possible future work includes examining the accuracy of added resistance predictions using three-dimensional methods and comparing them against the present strip theory implementation.

Contents

Abstract	ii
Executive Summary	iii
Table of Contents	iv
Notation	v
1 Introduction	1
2 Background	1
3 Theory	2
4 Added Resistance in Head Seas for Series 60 Hull Forms	6
5 Added Resistance in Head and Oblique Seas for FFG 7 Frigate	11
6 Influence of Swell-Up Corrections on Added Resistance	20
7 Conclusions	29
References	31

Notation

A_x	sectional area
a	wave amplitude
B	ship beam
C_B	block coefficient
F_n	Froude number
g	gravitational acceleration
h	elevation of steady wave due to ship forward speed
L	ship length between perpendiculars
n_x, n_y, n_z	components of normal vector pointing into ship
p	pressure
R_{AW}	added resistance in waves
R'_{AW}	added resistance in unit amplitude waves
R_{AW}^{lw}	added resistance in long waves
R_{AW}^{sw}	added resistance in short waves
S	ship surface
$S(\beta_s, \omega)$	wave directional spectral density
T	ship draft
U	ship forward speed
wl	ship waterline
wl^*	portion of ship waterline exposed to incident waves
x, y, z	coordinate system
α	swell correction weighting factor
β_s	sea direction
ζ_D	diffracted wave elevation
ζ_I	incident wave elevation
ζ_r	relative motion
η_i	ship motion for mode i
θ	angle of ship waterline relative to x axis
λ	wavelength
ρ	water density
ω	wave frequency
ω_e	wave encounter frequency
Δ	ship mass displacement

1 Introduction

The resistance of a ship travelling through waves is known to be greater than the ship resistance in calm water. This resistance due to waves, commonly called added resistance, arises from the temporal average of the unsteady surge force acting on the ship. Added resistance is important in ship design because it can increase propulsion requirements for a ship which must achieve a specified speed in a seaway. The increased propeller speed required to overcome added resistance will also lower cavitation speed. This report describes the prediction of ship added resistance in waves through implementation of the theory of Faltinsen et al. [1] into DREA's strip theory code SHIPMO7 [2].

The following section contains background information, including a review of previous work on added resistance in waves. The added resistance theory of Faltinsen et al. [1] is then given using the notation conventions of the SHIPMO theoretical formulation from Schmitke and Whitten [3]. Comparisons with experimental data for four different ships are used to assess the validity of the theoretical method in head and oblique seas. Further comparisons illustrate the effect of swell-up due to ship forward speed on added resistance predictions. Finally, recommendations are made regarding the applicability of the current method to added resistance computations for ship design.

2 Background

The steady wave drift force acting on a ship is the temporal average of the unsteady wave forces. Added resistance is the longitudinal component of the steady wave drift force. Since added resistance is a second-order phenomenon, it is significantly more difficult to predict than first-order phenomena such as ship motions.

Before describing the available literature, it is useful to distinguish between far-field and near-field methods for computing added resistance. A far-field method considers the mean rate of wave energy being radiated away from a ship travelling in a seaway. The term far-field arises because momentum flux is evaluated across a vertical control surface of infinite radius surrounding the ship. Not surprisingly, far-field equations for predicting added resistance include ship hydrodynamic damping terms. In contrast, near-field methods obtain wave drift force by direct integration of the pressure distribution on the ship surface. As will be shown in the next section, the wave drift force from near-field methods is largely determined by the ship relative motion.

Many authors have examined added resistance using far-field methods. Havelock [4] and Maruo [5] were among the first to present theories for predicting added resistance in waves. Gerritsma and Beukelman's method [6] for added resistance in head seas has become popular because it is relatively simple to implement in strip theory codes. Salvesen [7, 8] also gives a prediction method compatible with strip theory programs. Unlike Gerritsma and Beukelman's method, Salvesen's method can predict added resistance for oblique wave directions. Fang [9] recently published an extension to Salvesen's theory, which is reported to give better results. An alternative strip theory method is given by Lin and Reed [10].

Near-field methods are given by Faltinsen et al. [1], Hearn et al. [11], and Hsiung and Huang [12]. Hearn et al. present computations for both near and far-field methods implemented into a three-dimensional ship motion program. Their results indicate that the near-field method gives

results superior to the far-field method.

Relatively few experimental data exist for added resistance in waves. Head seas data from Gerritsma and Beukelman [6] and Strom-Tejsen et al. [13] have been used for validation in References 1, 6, 7, and 11. O'Dea and Kim [14] provide a rare source of experimental data for oblique seas.

McTaggart [15] tried an implementation of Salvesen's far-field method [7] in SHIPMO5. Comparisons with Salvesen's computations indicated that the theory was correctly implemented; however, the method was not permanently implemented into SHIPMO because of poor agreement with experiments in many cases, particularly in oblique seas. It is postulated that errors in the added resistance predictions were largely due to inaccuracies in hydrodynamic coefficients and motions predicted by strip theory, which assumes low Froude number, high wave frequency, and slender ship geometry.

DMSS sponsored the implementation of a near-field added resistance capability into SMCA, a three-dimensional ship motion code developed by Hsiung and Huang [12, 16]. SMCA gives good predictions of added resistance for a few sample cases; however, more validation is required. Unlike most three-dimensional ship motion programs, SMCA can include the diffraction component of the steady forward speed potential when evaluating the hydrodynamic " m " terms. The inclusion of full m terms should give improved predictions of ship motions, sea loads, and added resistance at forward speed; however, results in Reference 12 indicate uncertainty regarding the benefits of using full m terms compared with the more commonly used simplified m terms.

This technical memorandum examines the implementation of the near-field method of Faltinsen et al. [1] into SHIPMO7. The implementation of a near-field method into SHIPMO7 was prompted by several factors. Although Reference 15 showed that a far-field method gave limited success, strip theory generally gives better predictions of relative motion than of damping coefficients; thus, a near-field method based on the ship relative motion would likely be more accurate with strip theory than a far-field method. Hearn's results with a three-dimensional code also indicate that a near-field method is more accurate. In comparison to SMCA, SHIPMO7 is more robust, has easier input preparation, and requires much less computation time. Consequently, SHIPMO7 is preferable to SMCA if the two codes produce predictions of similar accuracy. Another factor in support of the near-field method is that its implementation into SHIPMO7 was straightforward, requiring only the addition of a small number of lines to the code.

3 Theory

The added resistance theory implemented in SHIPMO7 is described in detail in Reference 1. This section gives the equations from Reference 1 using SHIPMO notation (see Reference 3); thus, the original equations are slightly modified. The SHIPMO coordinate system is shown in Figure 1 and the wave direction β_s is defined according to Figure 2.

The near-field method predicts added resistance in waves using the following equation:

$$R_{AW} = - \int_S \overline{p n_x} dS \quad (3.1)$$

where S is the wetted surface of the ship, p is hydrodynamic pressure, and n_x is the x component of the normal vector pointing into the ship. The line over $p n_x$ indicates the time average. In

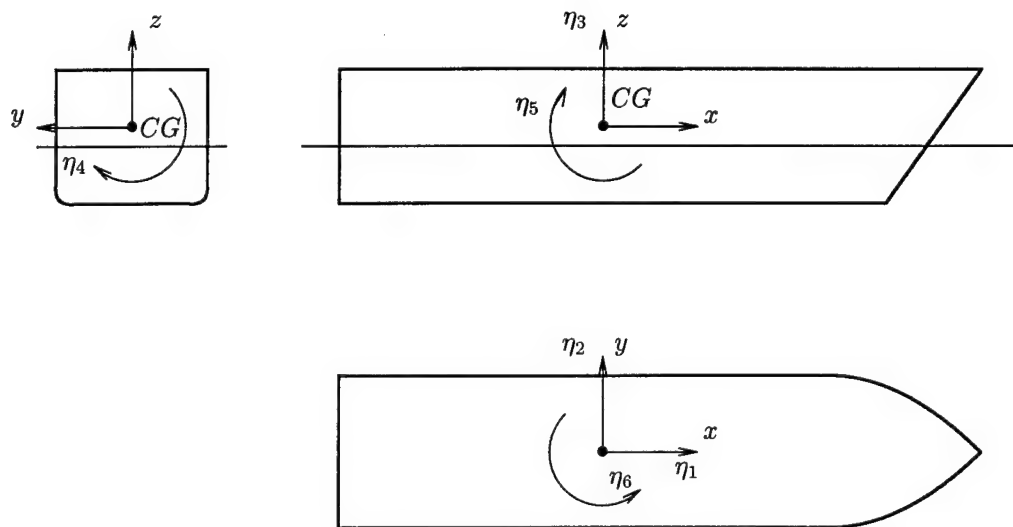


Figure 1: SHIPMO Coordinate System

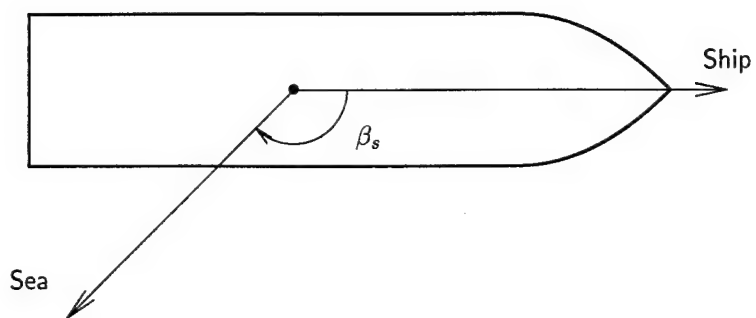


Figure 2: Definition of SHIPMO Wave Direction

practice, the above equation must be evaluated very carefully because the terms within the integral tend to nullify each other, with added resistance being the final residual.

As indicated by References 1 and 11, the dominant term in the near-field method is the following integral taken about the ship waterline:

$$R_{AW} = -\frac{\rho g}{2} \int_{wl} \overline{\zeta_r^2(x, y, t)} n_x dl \quad (3.2)$$

where wl is the ship waterline and $\zeta_r(x, y, t)$ is the relative motion. Neglecting the effect of dynamic swell-up due to ship forward speed, the relative motion can be expressed as:

$$\zeta_r = \zeta_I + \zeta_D - \eta_3 - y\eta_4 + x\eta_5 \quad (3.3)$$

where ζ_I is the incident wave elevation, ζ_D is the diffracted wave elevation, η_3 is ship heave, η_4 is ship roll, and η_5 is ship pitch. As discussed in References 2 and 17, the relative motion can be re-written to include the effect of swell-up due to forward ship speed as follows:

$$\zeta_r = \left(1 + \frac{\partial h(x, U)}{\partial T}\right) (\zeta_I + \zeta_D - \eta_3 - y\eta_4 + x\eta_5) \quad (3.4)$$

where $h(x, U)$ is the steady wave elevation along the ship due to forward speed and T is ship draft.

The greatest problem in applying Equation (3.2) to predicting added resistance is that strip theory cannot evaluate the diffracted wave elevation ζ_D . Fortunately, Reference 1 gives two different near-field equations for determining added resistance within this limitation of strip theory. When wavelength is of the order of ship length or greater, ship motions will be significant but diffraction effects will be negligible (i.e. $\zeta_D \approx 0$). The added resistance in long waves will then be based on Equation (3.2), which is re-formulated to account for the displacement of the ship axes due to ship motions:

$$R_{AW}^{lw} = -\frac{\rho g}{2} \int_{wl} \overline{\zeta_r^2(x, y, t)} n_x dl - \omega_e^2 \Delta \overline{\eta_3 \eta_5} + \omega_e^2 \Delta \overline{\eta_2 \eta_6} \quad (3.5)$$

where ω_e is wave encounter frequency and Δ is ship mass. Within SHIPMO, the relationships between the time averages and complex RAOs are:

$$\overline{\zeta_r^2} = \frac{1}{2} |\zeta_r|^2 \quad (3.6)$$

$$\overline{\eta_3 \eta_5} = \frac{1}{2} (\text{Real}\{\eta_3\} \text{Real}\{\eta_5\} + \text{Imag}\{\eta_3\} \text{Imag}\{\eta_5\}) \quad (3.7)$$

$$\overline{\eta_2 \eta_6} = \frac{1}{2} (\text{Real}\{\eta_2\} \text{Real}\{\eta_6\} + \text{Imag}\{\eta_2\} \text{Imag}\{\eta_6\}) \quad (3.8)$$

As wavelength approaches zero, ship motions approach zero but diffraction effects (including wave reflection) become important. Figure 3 illustrates that diffraction effects will cause wave elevation to approach zero on the lee side of a body. SHIPMO7 uses the following equation adapted from Reference 1 for predicting added resistance in short waves:

$$R_{AW}^{sw} = -\frac{\rho g}{2} \int_{wl} \overline{\zeta_I^2(x, y, t)} n_x \times \left\{ \sin^2(\theta + \pi - \beta_s) + \frac{2\omega U}{g} [1 - \cos \theta \cos(\theta + \pi - \beta_s)] \right\} dl \quad (3.9)$$

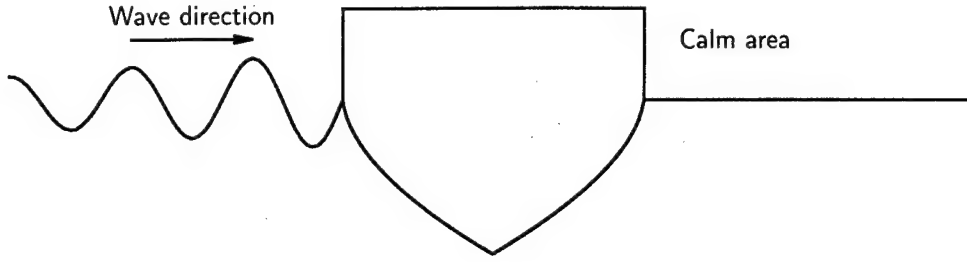


Figure 3: Influence of Diffraction on Wave Elevation in Vicinity of Body

where wl^* is the portion of the ship waterline exposed to the incident waves and θ is:

$$\theta = \tan^{-1} \frac{n_x}{n_y} \quad (3.10)$$

If $d\theta/dl$ is continually increasing or decreasing about the ship waterline, which is the case for most ships, then the segment dl on the waterline will be exposed to the incident waves if the difference between $|\tan^{-1} n_y/n_x|$ and $-\beta_s$ is less than 90 degrees.

With a strip theory code such as SHIPMO, no rational method exists for determining added resistance in the transition region between the short and long wave regimes; however, the following equation gives reasonable results using the short and long wave equations:

$$R_{AW} = \begin{cases} R_{AW}^{lw} & \text{for } \lambda/L \geq 1 \\ \max(R_{AW}^{lw}, R_{AW}^{sw}) & \text{for } \lambda/L < 1 \end{cases} \quad (3.11)$$

For a ship in irregular seas, the mean added resistance can be evaluated using the following equation from Salvesen:

$$R_{AW} = 2 \int_0^\infty \int_{-\pi}^\pi R'_{AW}(\beta_s, \omega) S(\beta_s, \omega) d\beta_s d\omega \quad (3.12)$$

where R'_{AW} is added resistance in unit amplitude regular waves and $S(\beta_s, \omega)$ is wave elevation spectral density.

4 Added Resistance in Head Seas for Series 60 Hull Forms

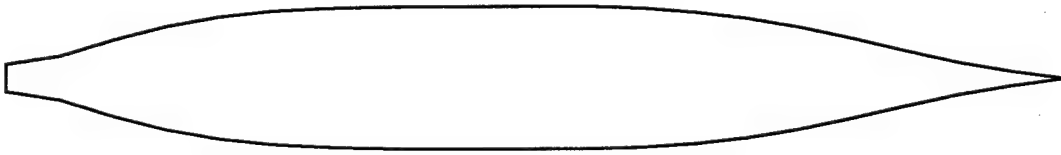
The Series 60 hull form series described in Reference 18 has been the subject of several added resistance studies. Table 1 gives dimensions for the models considered in the present investigation, while Figure 4 gives waterplanes which illustrate the slenderness of the ships. Strom-Tejsen et al. [13] measured added resistance in regular head seas for Series 60 models. Salvesen [7] used these experimental results to validate his theory, which was tested with SHIPMO5 [15]. The implementation of Salvesen's theory in SHIPMO5 was shown to be correct and gave good agreement with experiments for Series 60 models. Hearn et al. [11] compared predictions from three-dimensional near-field and far-field methods with Series 60 experimental data. The comparisons indicate that their near-field method is superior to their far-field method. Hsiung and Huang [12] obtained good agreement with experimental data for two Series 60 forms using SMCA4.

Table 1: Dimensions for Series 60 Models

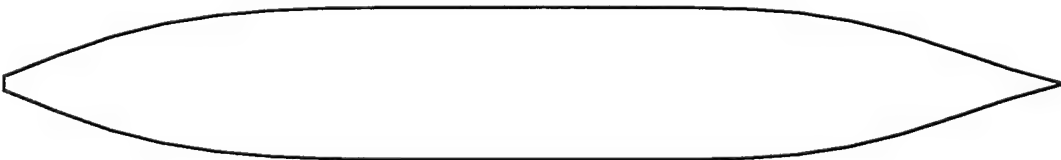
	$C_B = 0.60$	$C_B = 0.70$	$C_B = 0.80$
Length, L (m)	121.9	121.9	121.9
Beam, B (m)	16.25	17.42	18.76
Draft, T (m)	6.50	6.97	7.50
Length/Beam, L/B	7.50	7.00	6.60
Beam/Draft, B/T	2.50	2.50	2.50

Figure 5 to 10 show comparisons between numerical predictions and experimental data for Series 60 models. SHIPMO7 over-predicts added resistance for almost all cases. The figures include three dimensional results from Hearn's near-field method and from SMCA4 using full m -terms. The three dimensional codes do not give significantly better results than SHIPMO7. The Series 60 results indicate that Equation (3.11) provides a reasonable method for combining long and short wavelength predictions of added resistance.

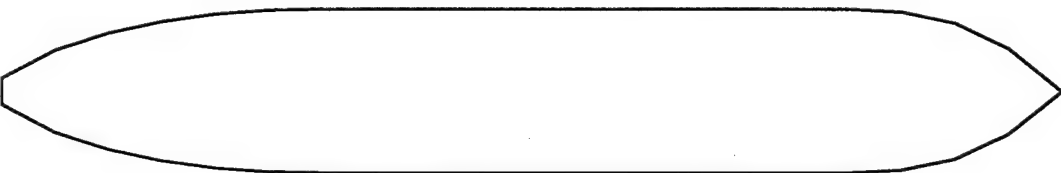
Series 60, $C_B = 0.60$



Series 60, $C_B = 0.70$



Series 60, $C_B = 0.80$



FFG 7

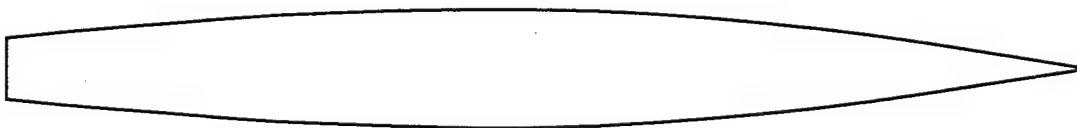


Figure 4: Waterplanes of Series 60 Ships and *FFG 7*

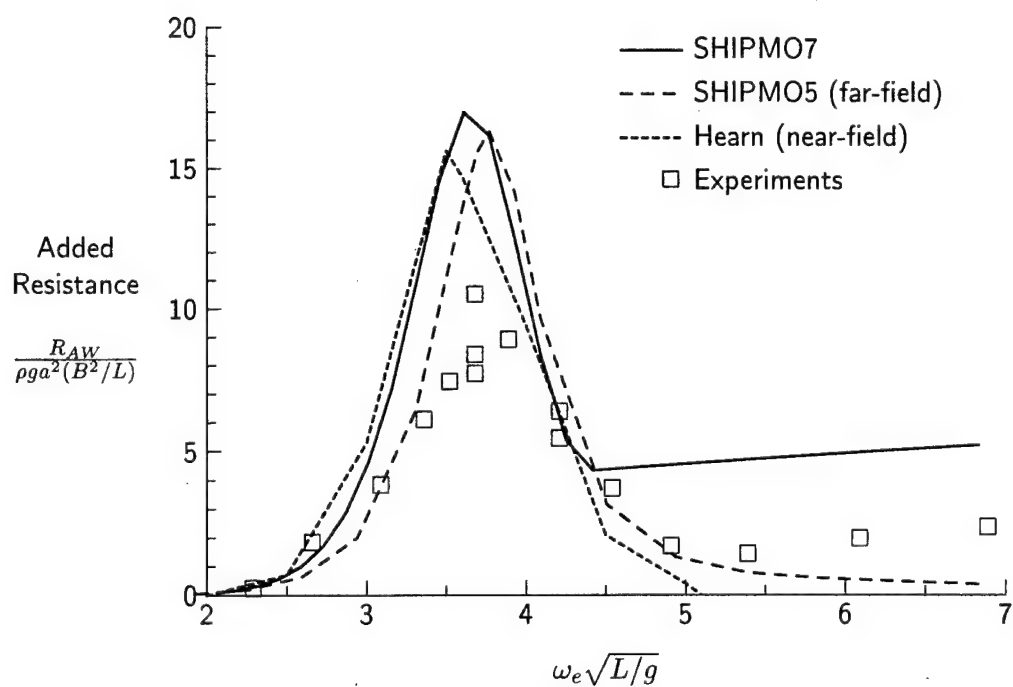


Figure 5: Added Resistance in Head Seas for Series 60, $C_B = 0.60$, $Fn = 0.266$

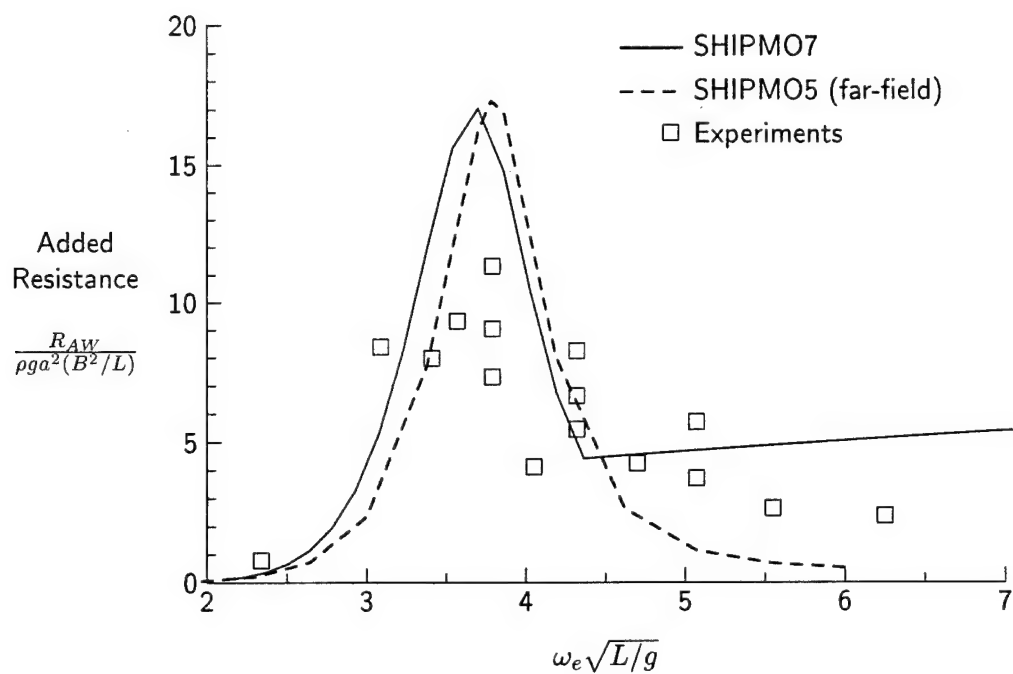


Figure 6: Added Resistance in Head Seas for Series 60, $C_B = 0.60$, $Fn = 0.283$

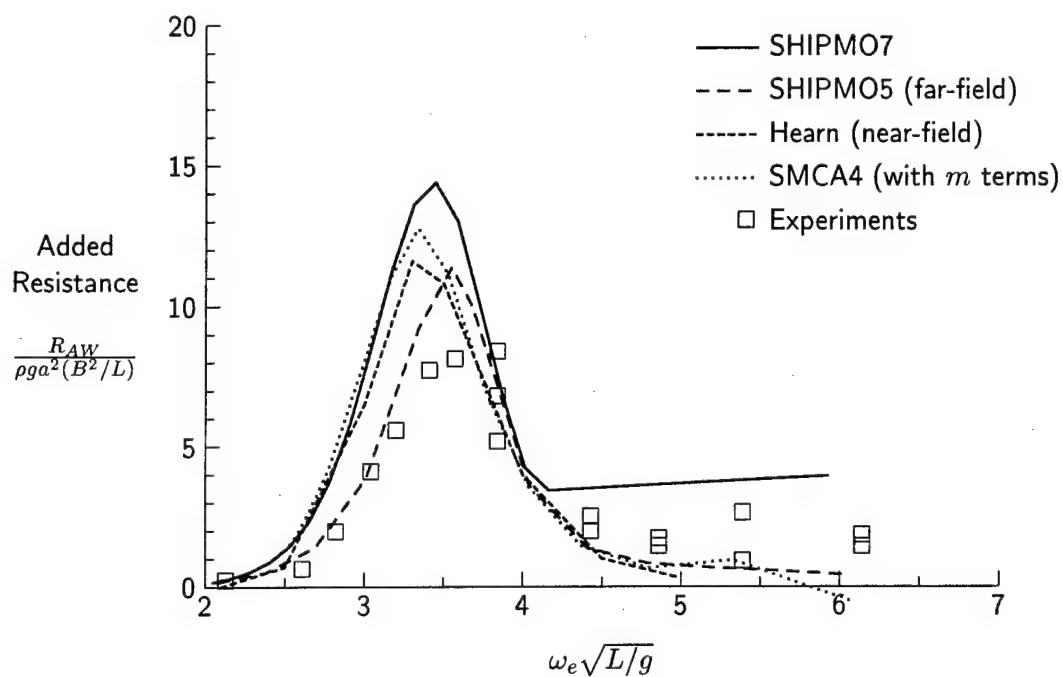


Figure 7: Added Resistance in Head Seas for Series 60, $C_B = 0.70$, $Fn = 0.207$

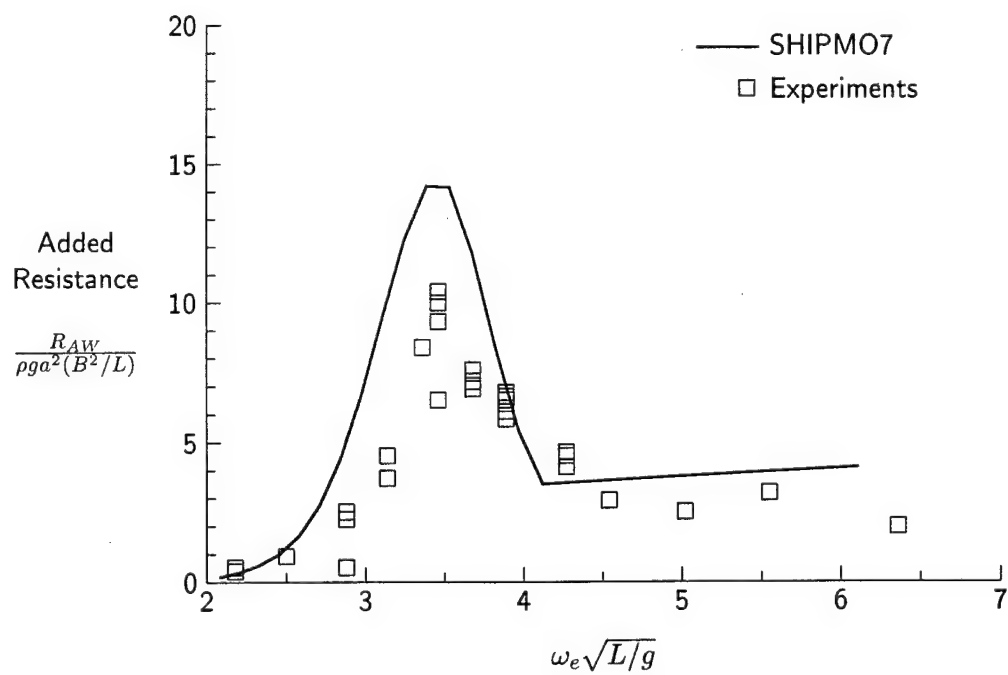


Figure 8: Added Resistance in Head Seas for Series 60, $C_B = 0.70$, $Fn = 0.222$

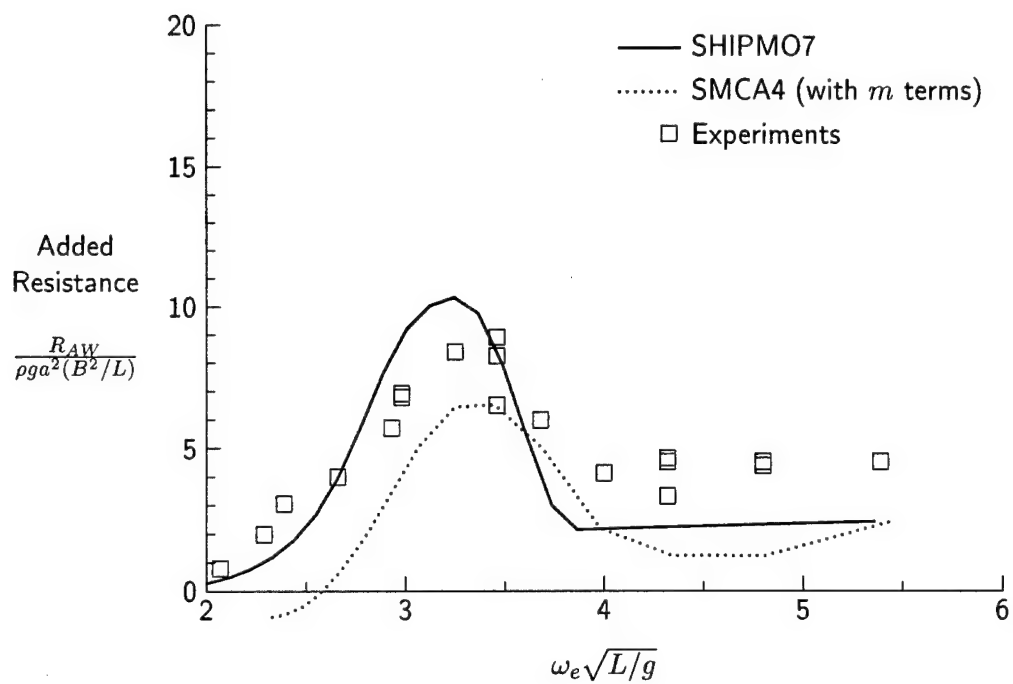


Figure 9: Added Resistance in Head Seas for Series 60, $C_B = 0.80$, $Fn = 0.147$

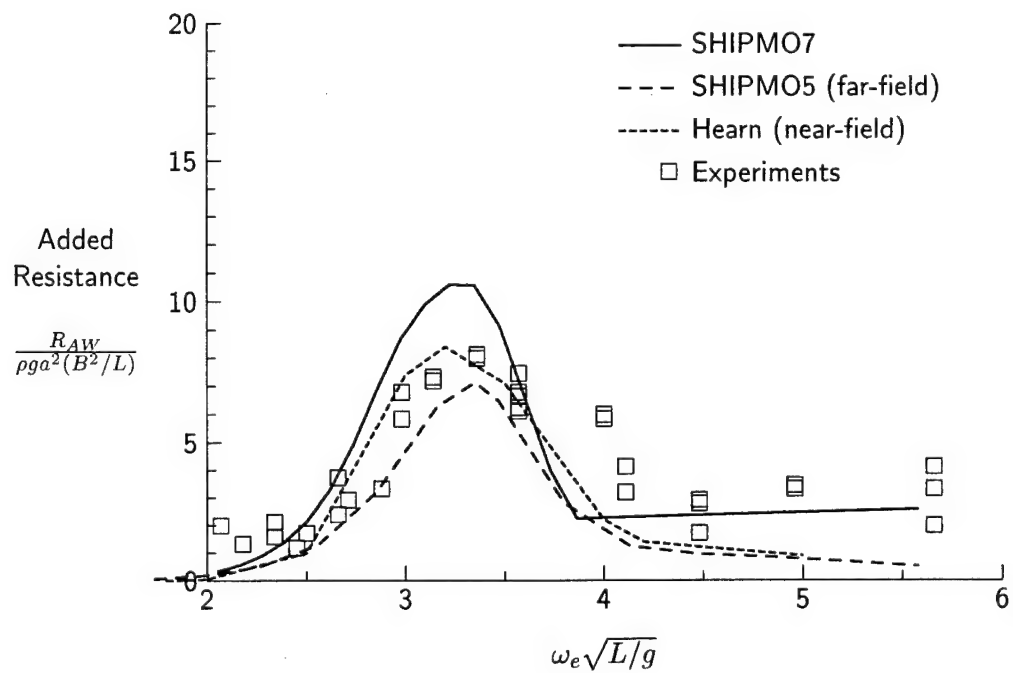


Figure 10: Added Resistance in Head Seas for Series 60, $C_B = 0.80$, $Fn = 0.165$

5 Added Resistance in Head and Oblique Seas for FFG 7 Frigate

To assess the validity of the SHIPMO7 added resistance implementation for fine hull forms, comparisons with experimental results were made for an American *FFG 7* frigate. Figure 4 shows the waterplane of the *FFG 7*, with dimensions given in Table 2. O'Dea and Kim [14] give experimental added resistance results for the *FFG 7* and a comparison with numerical predictions based on the far-field strip theory of Lin and Reed [10]. These results are shown in Figures 11 to 26 along with predictions from SHIPMO5 and SHIPMO7.

Table 2: Dimensions for FFG 7 Frigate

Length, L (m)	124.4
Beam, B (m)	13.55
Draft, T (m)	4.37
Length/Beam, L/B	9.18
Beam/Draft, B/T	3.10
Block coefficient, C_B	0.45

Initial SHIPMO7 predictions of added resistance in oblique seas gave unrealistically high peaks when the wave encounter frequency was near the roll natural frequency of the ship. The source of these high added resistance values was very large roll motions because the SHIPMO7 data file for the *FFG 7* did not include any appendages. This problem was alleviated by adding bilge keels to the *FFG 7* such that the predicted roll motions were approximately equal to those given in Reference 19.

The SHIPMO7 added resistance predictions are generally lower than the experimental values. In most cases the SHIPMO7 values are similar to the SHIPMO5 far-field values. The greatest advantage of the SHIPMO7 predictions relative to predictions by SHIPMO5 and O'Dea and Kim is that SHIPMO7 gives nominally acceptable values for following seas (headings of 0 and 45 degrees) while SHIPMO5 and O'Dea and Kim give large negative values.

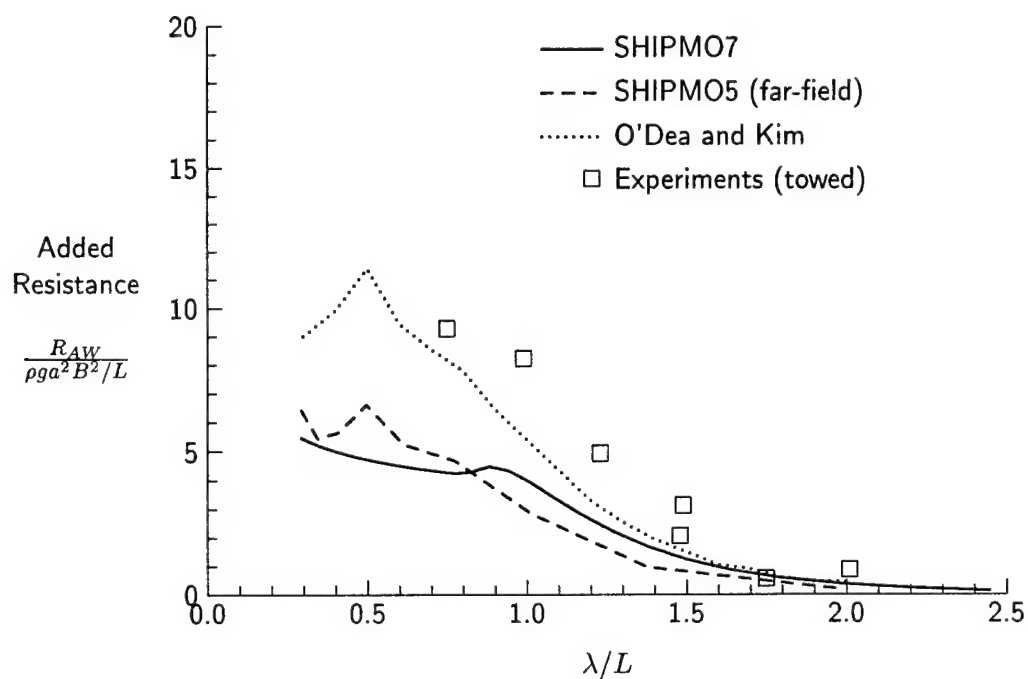


Figure 11: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 180 degrees

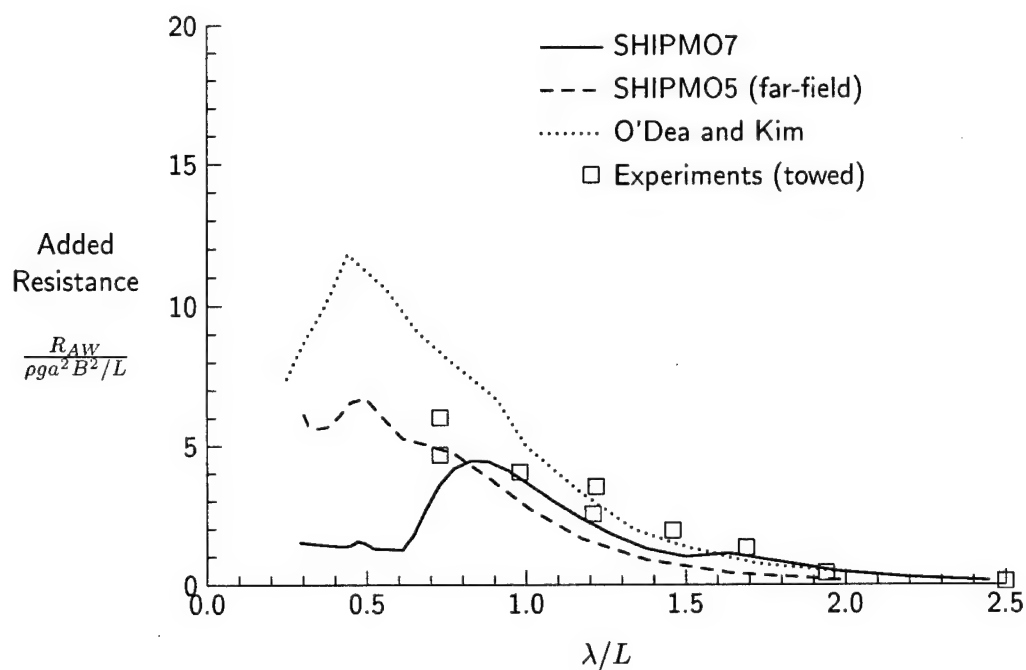


Figure 12: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 165 degrees

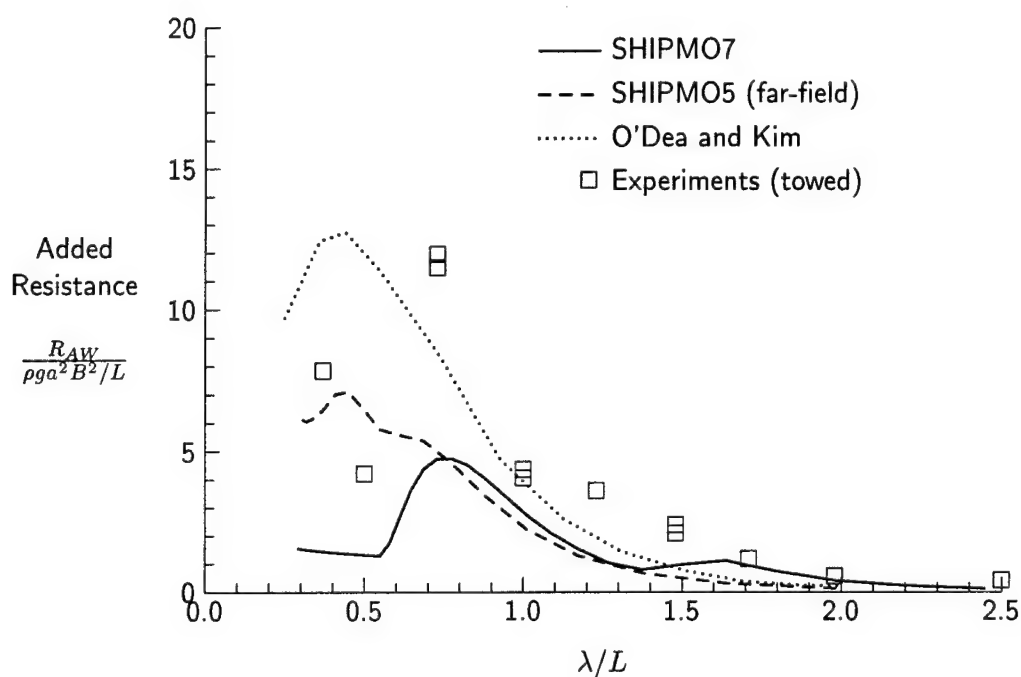


Figure 13: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 150 degrees

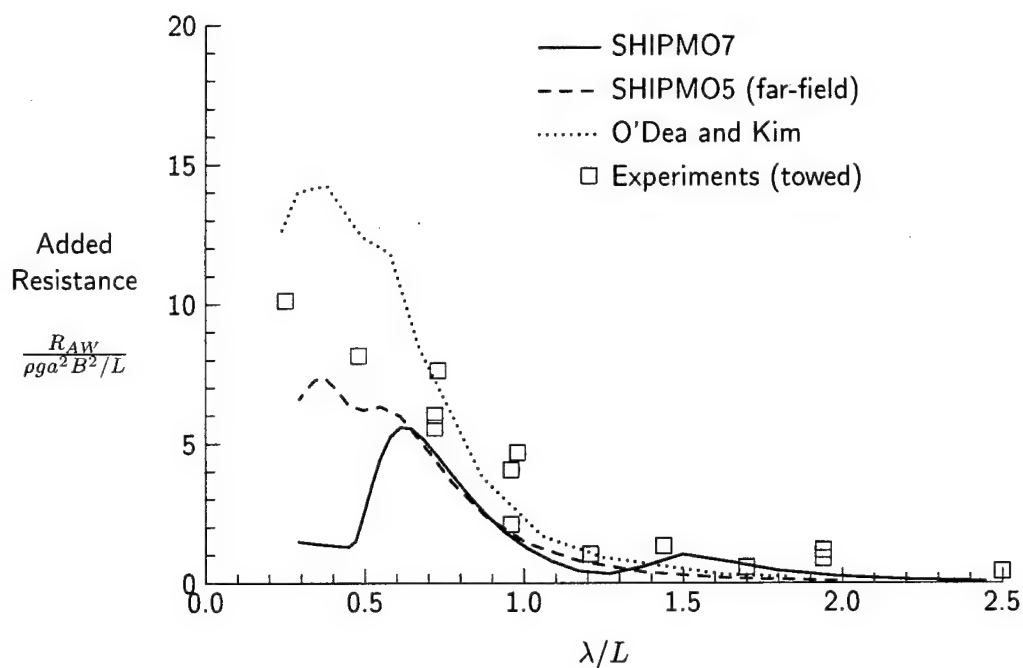


Figure 14: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 135 degrees

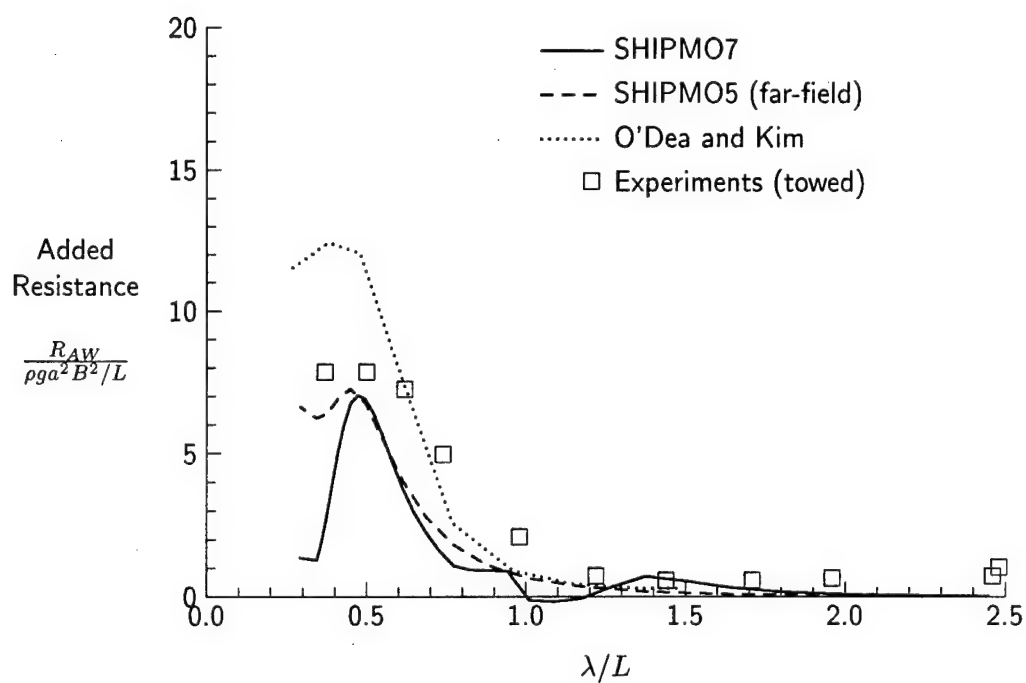


Figure 15: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 120 degrees

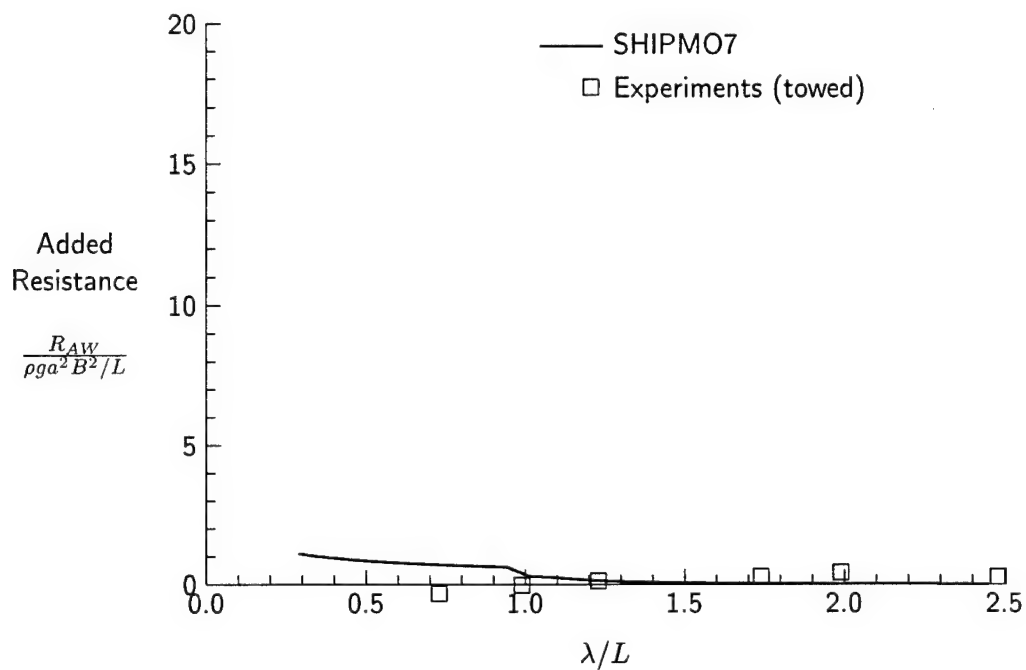


Figure 16: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 90 degrees

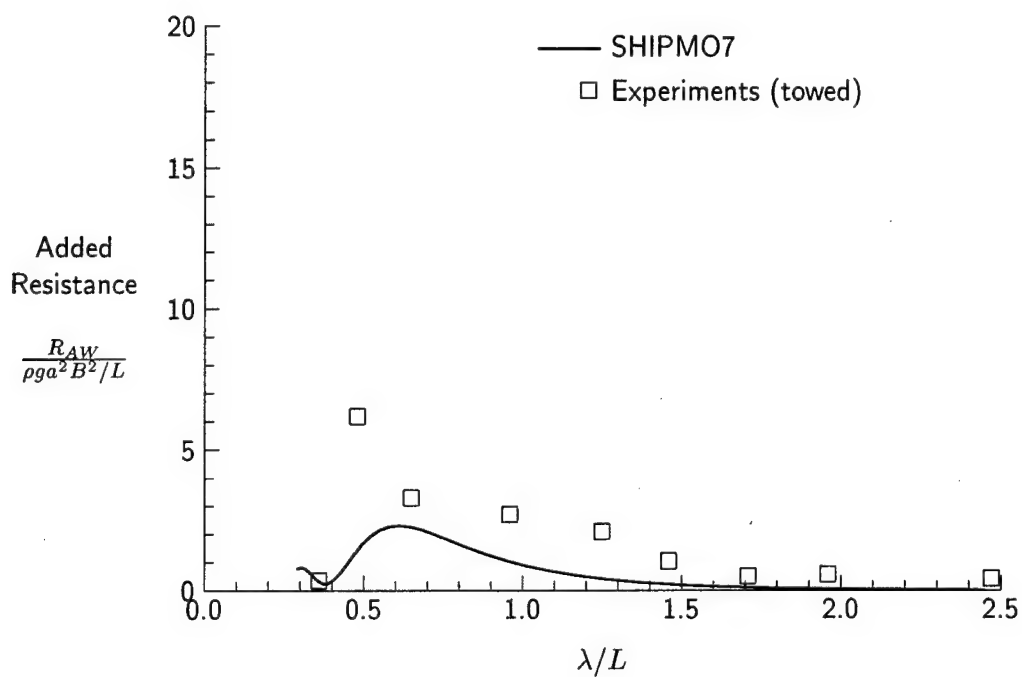


Figure 17: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 45 degrees

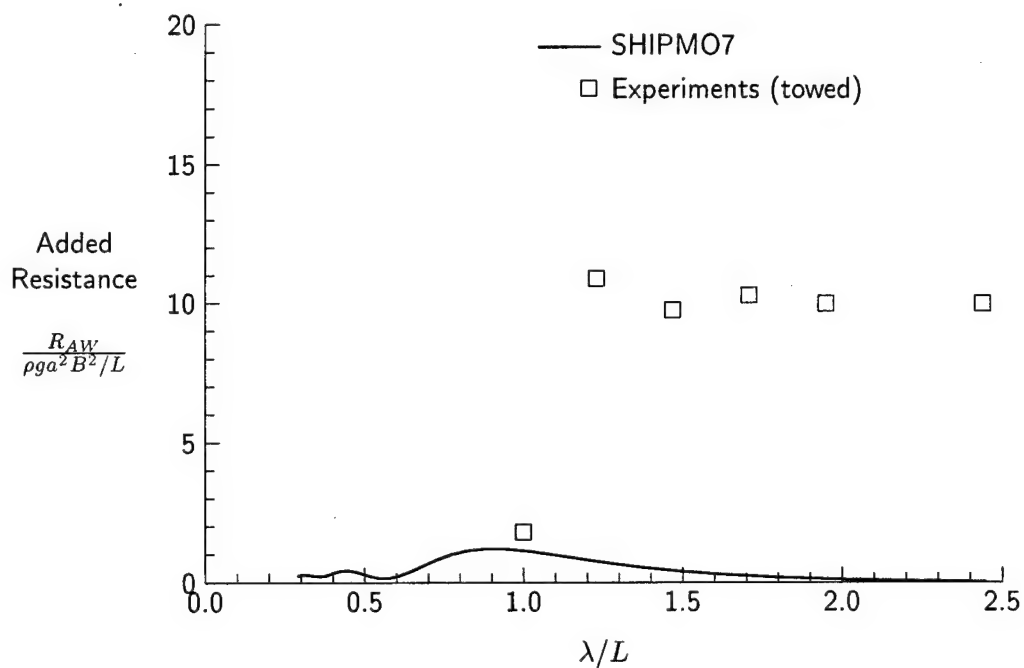


Figure 18: Added Resistance for *FFG 7*, $Fn = 0.15$, Heading = 0 degrees

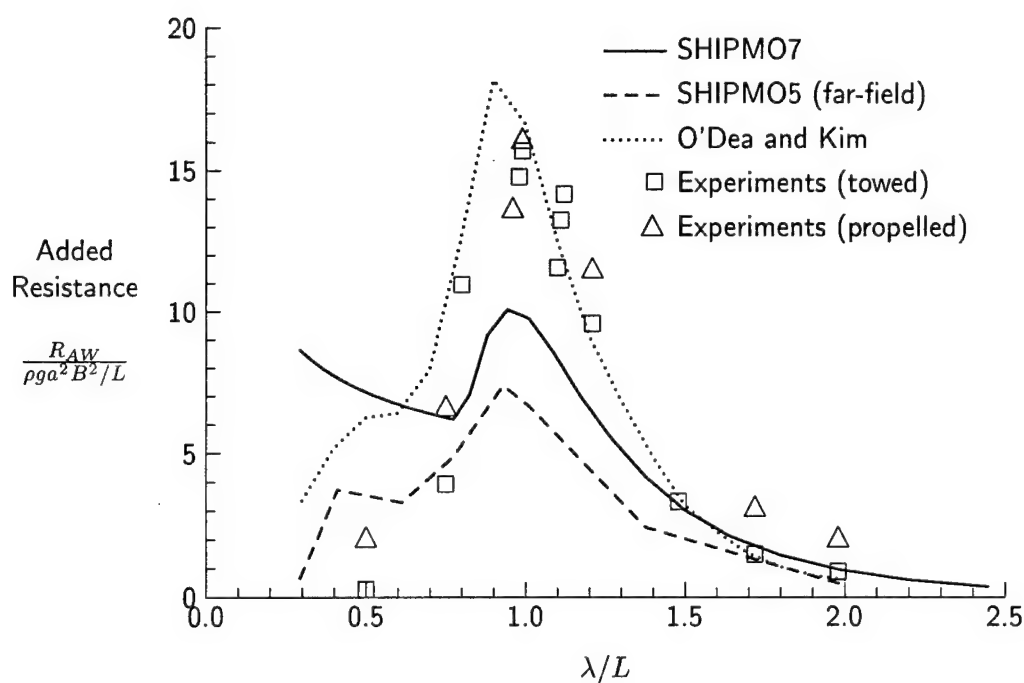


Figure 19: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 180 degrees

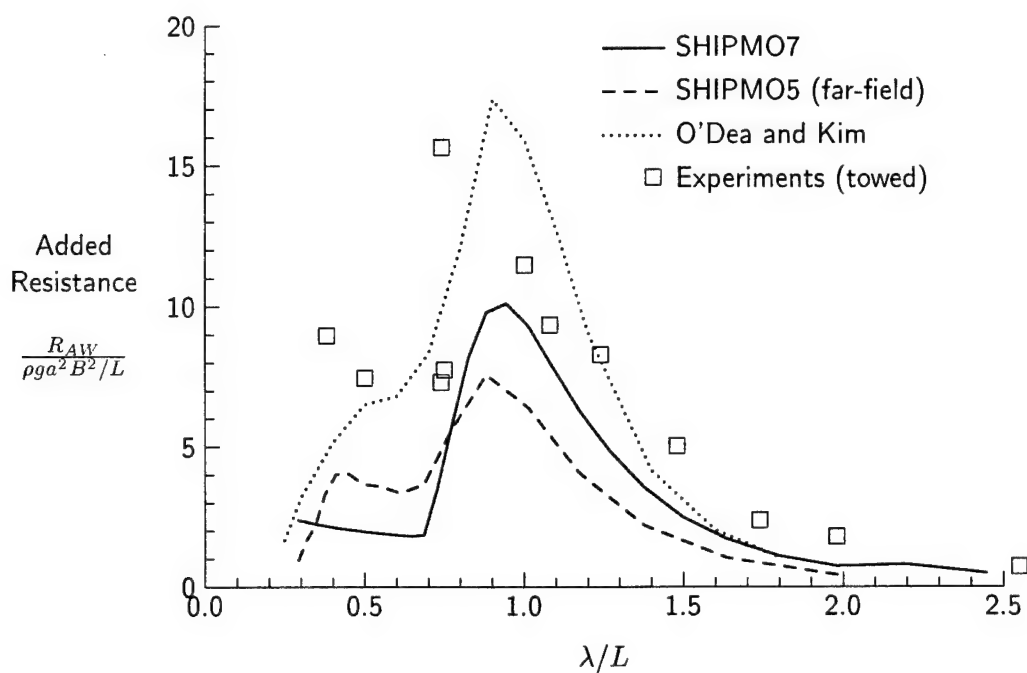


Figure 20: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 165 degrees

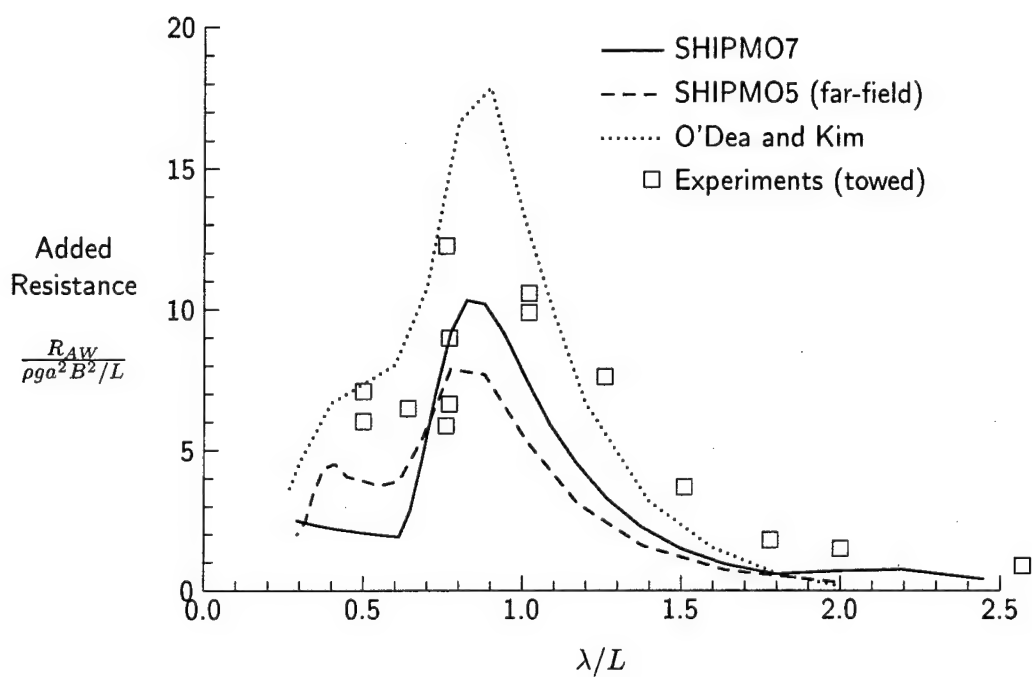


Figure 21: Added Resistance for FFG 7, $Fn = 0.30$, Heading = 150 degrees

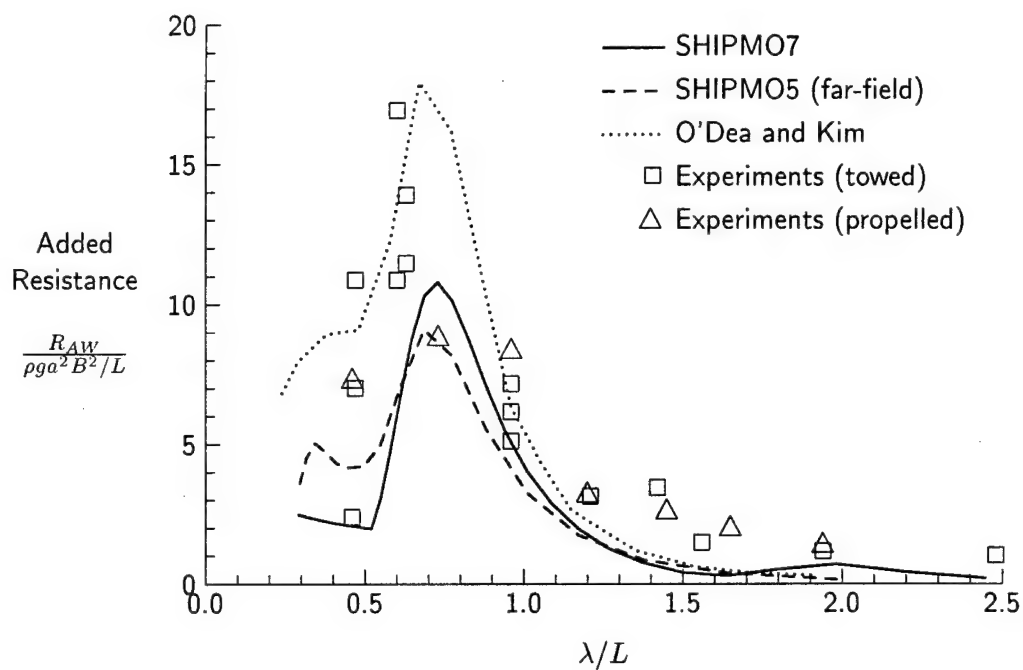


Figure 22: Added Resistance for FFG 7, $Fn = 0.30$, Heading = 135 degrees

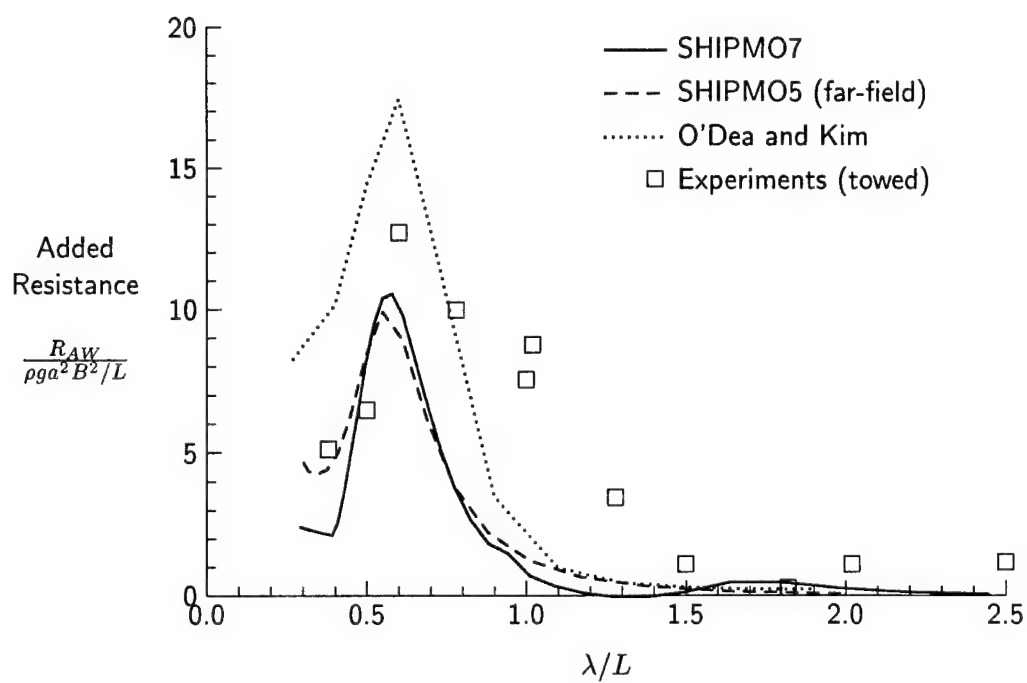


Figure 23: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 120 degrees

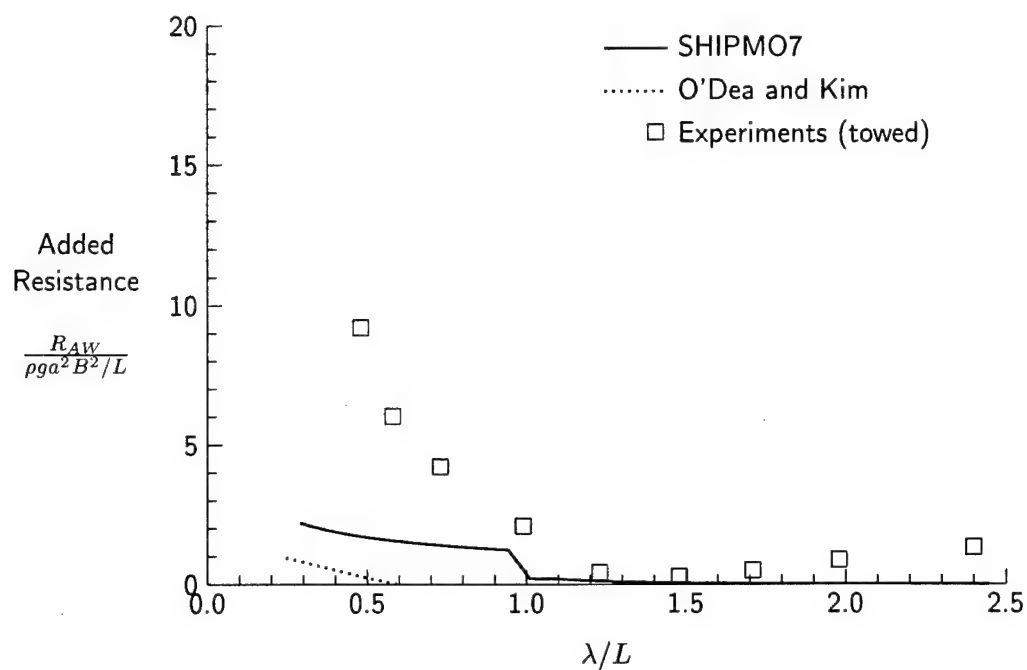


Figure 24: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 90 degrees

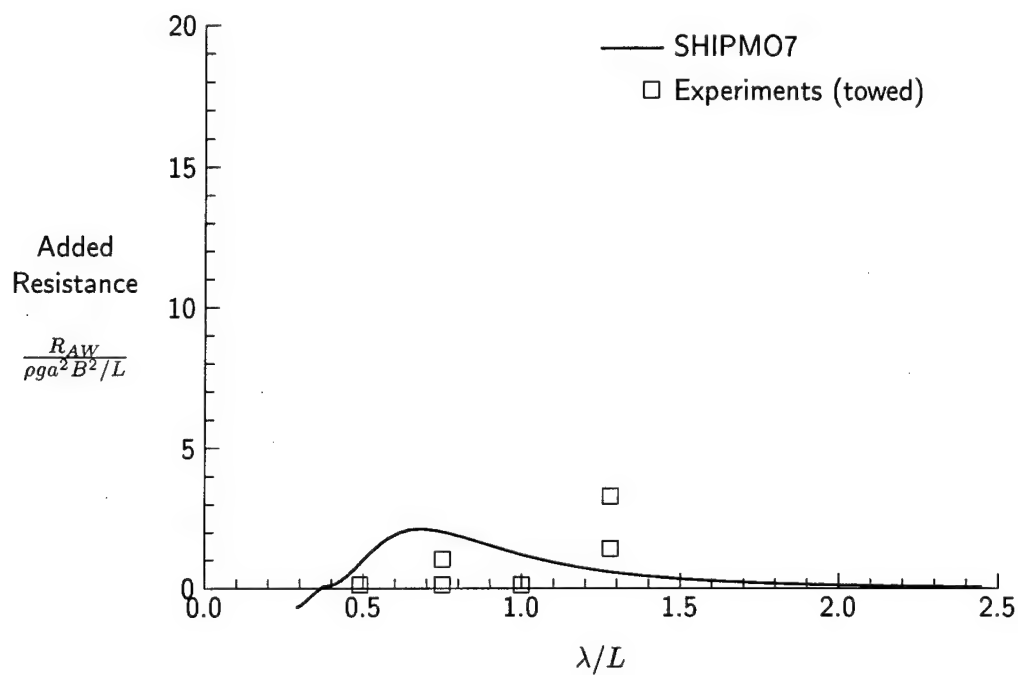


Figure 25: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 45 degrees

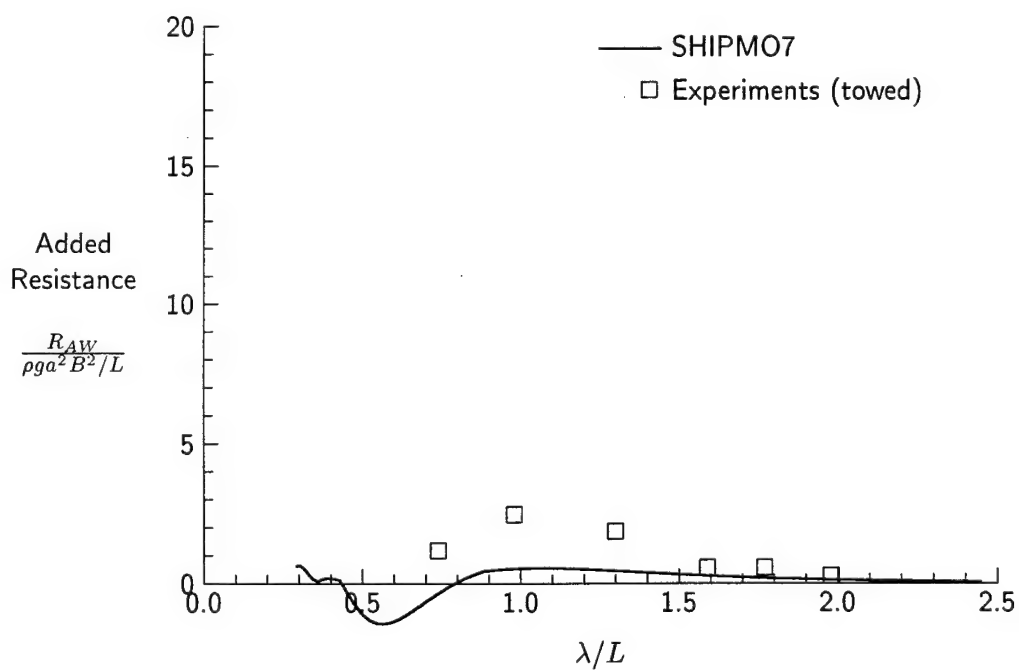


Figure 26: Added Resistance for *FFG 7*, $Fn = 0.30$, Heading = 0 degrees

6 Influence of Swell-Up Corrections on Added Resistance

The forward speed of a ship and resulting swell-up influences the relative motion and resulting added resistance. SHIPMO7 includes swell-up correction options using Equation (3.4). Computation of the swell-up coefficient $(1 + \partial h / \partial T)$ is based on the assumption that ship sectional area A_x varies gradually along the length of the ship. For a transom stern ship, this assumption is invalid near the stern and the swell-up prediction method gives poor results. In this case, SHIPMO7 can apply full swell-up correction along the forward half of the ship and a partial swell-up correction factor $(1 + \alpha \partial h / \partial T)$ along the aft half, with the weighting factor α varying linearly from unity at midships to zero at the stern. SHIPMO7 sets a limiting range of 0.5-2.0 for swell-up correction factors.

Figures 27 to 42 show swell-up coefficients and resulting added resistance predictions in head seas for the Series 60 ships and *FFG 7*, with station 0 at the forward perpendicular and station 20 at the aft perpendicular for each ship. Each ship has a transom stern; thus, the full SHIPMO7 swell-up correction should not be applied to any of them. Results for full swell-up corrections are given strictly for comparison.

The calculated swell-up coefficients confirm that the full swell-up correction gives erratic results near the stern for transom stern ships; the bow swell-up correction method gives reasonable results along the total length of the ship. In all cases, swell-up correction increases the resulting added resistance. For the Series 60 ships, the increased added resistance gives poorer agreement with experiments, while agreement improves for the *FFG 7*. Given that the more slender *FFG 7* is better suited to strip theory than the Series 60 ships, the results suggest that inclusion of swell-up correction provides improved modelling of the physics of added resistance in waves.

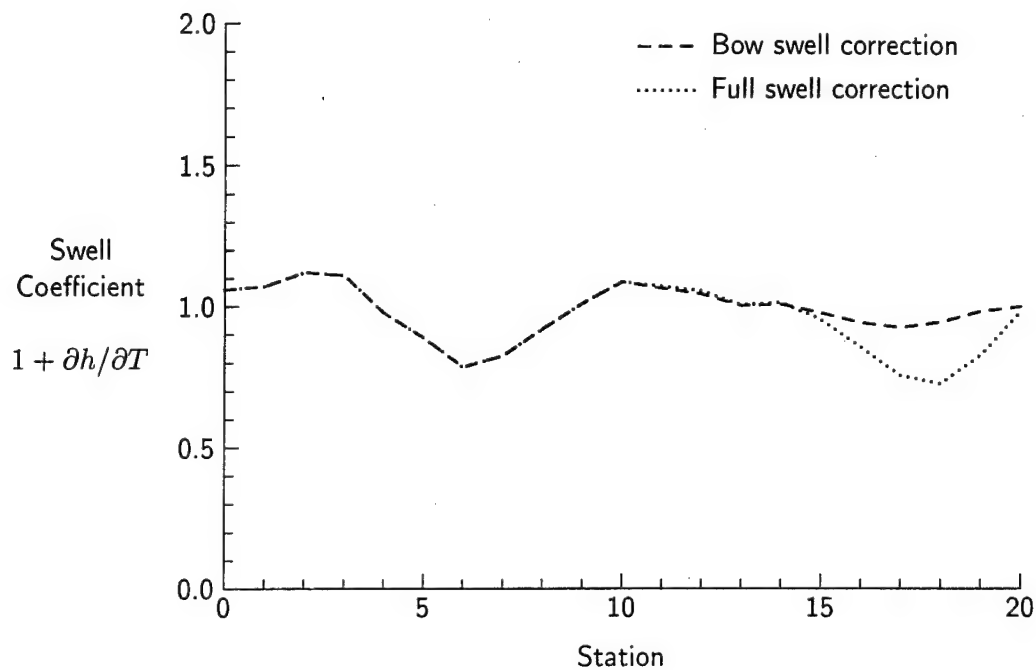


Figure 27: Swell-up Correction Factors for Series 60, $C_B = 0.60$, $Fn = 0.266$

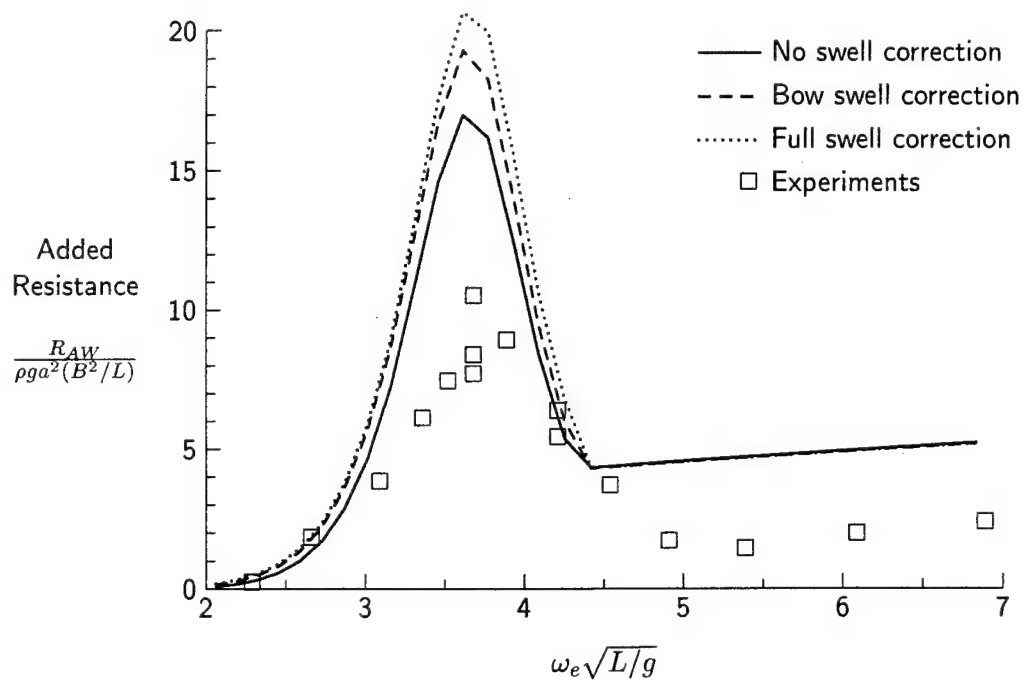


Figure 28: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.60$, $Fn = 0.266$

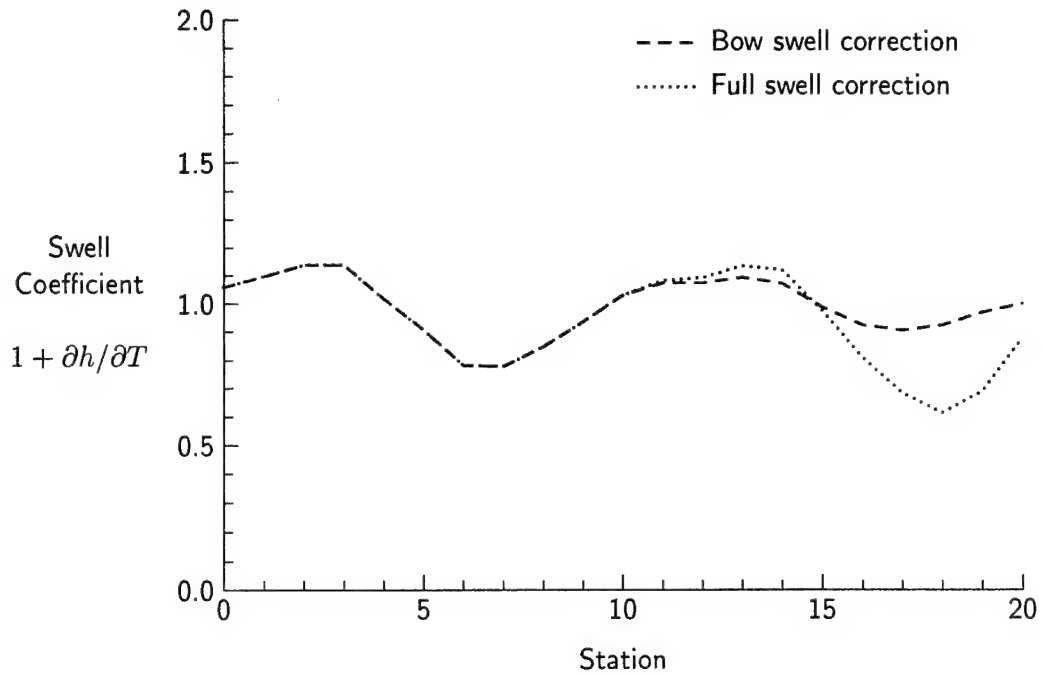


Figure 29: Swell-up Correction Factors for Series 60, $C_B = 0.60$, $Fn = 0.283$

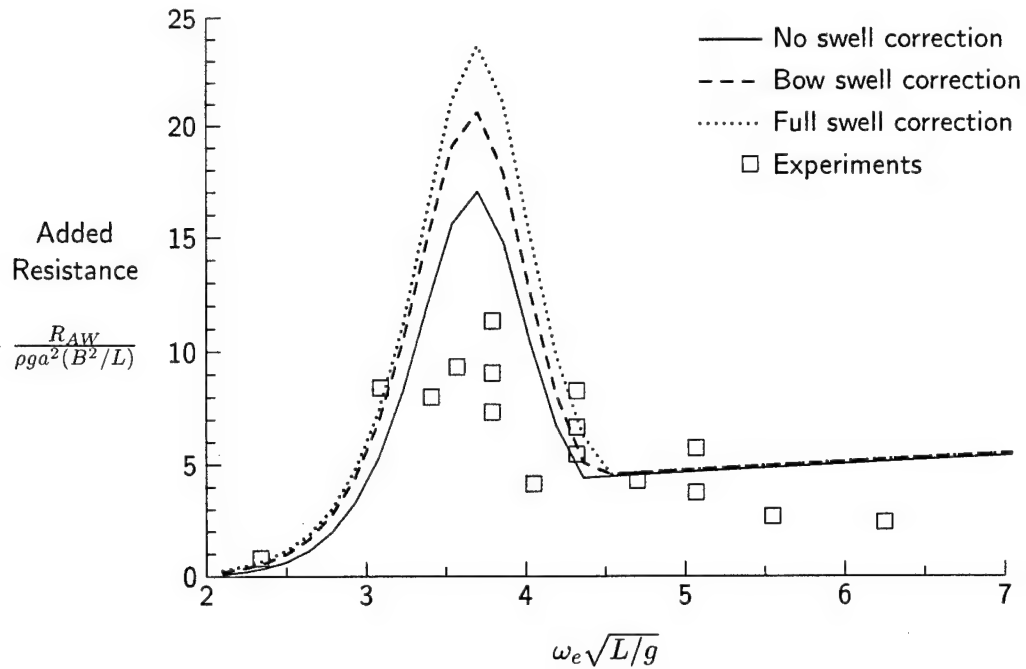


Figure 30: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.60$, $Fn = 0.283$

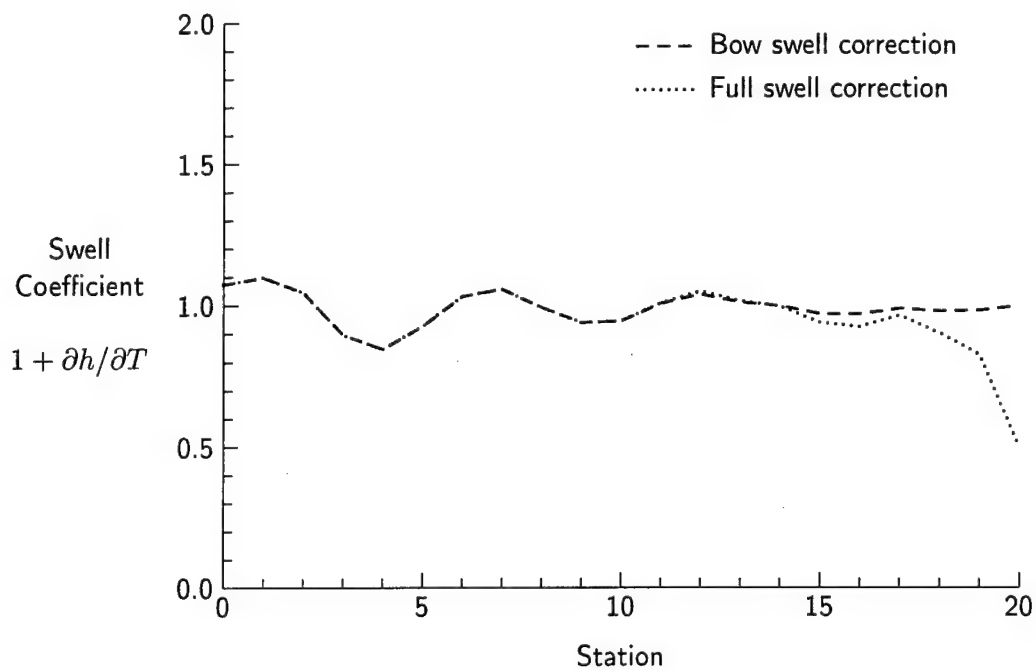


Figure 31: Swell-up Correction Factors for Series 60, $C_B = 0.70$, $Fn = 0.207$

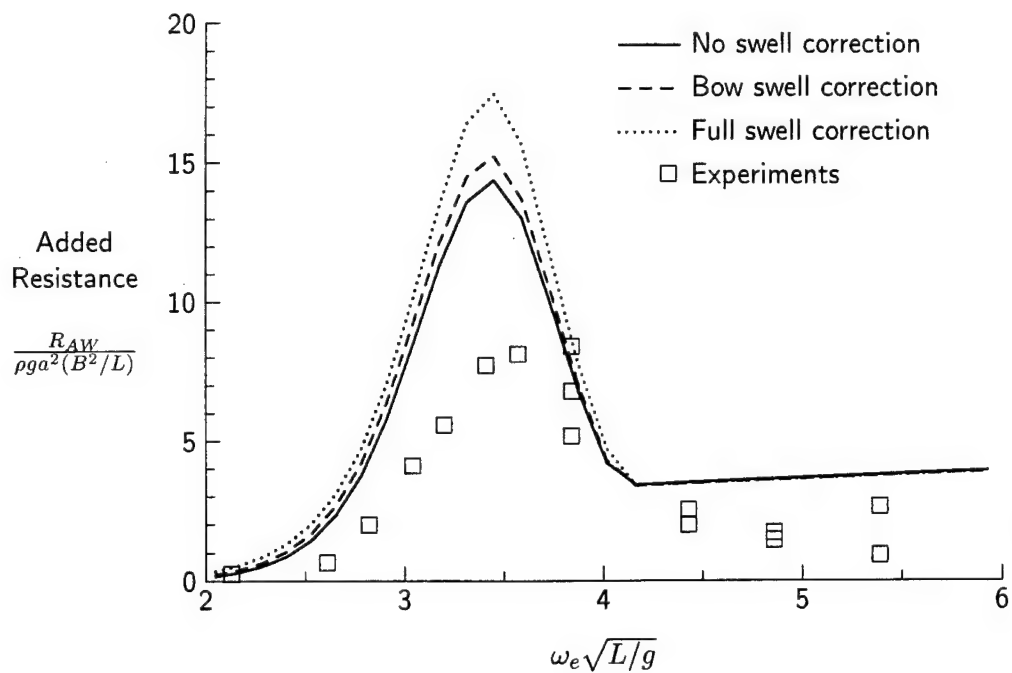


Figure 32: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.70$, $Fn = 0.207$

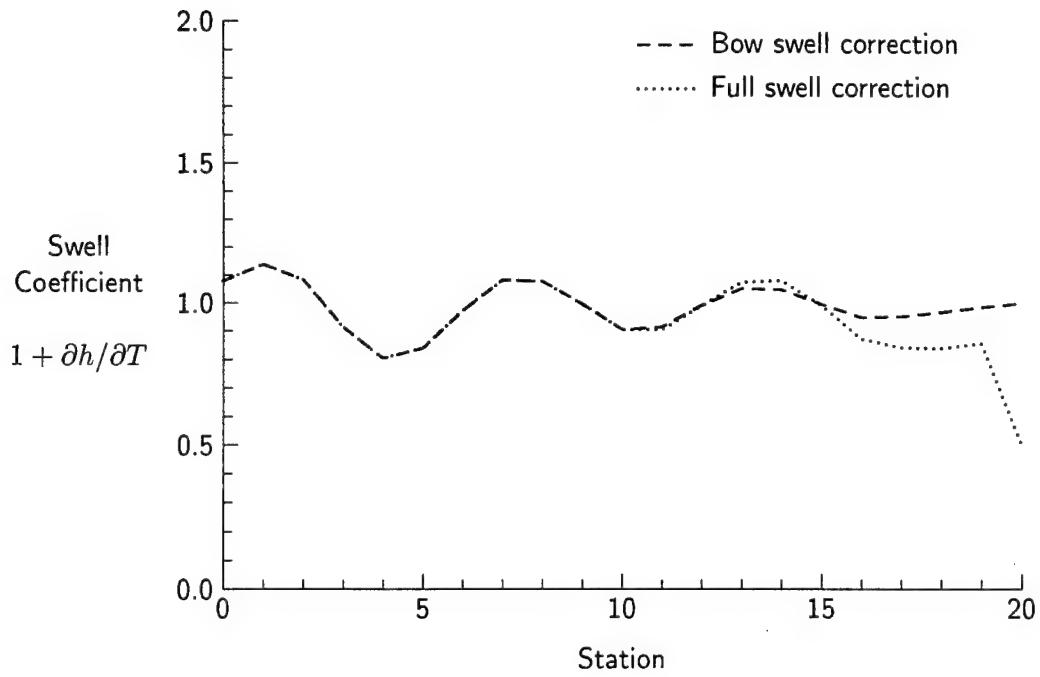


Figure 33: Swell-up Correction Factors for Series 60, $C_B = 0.70$, $Fn = 0.222$

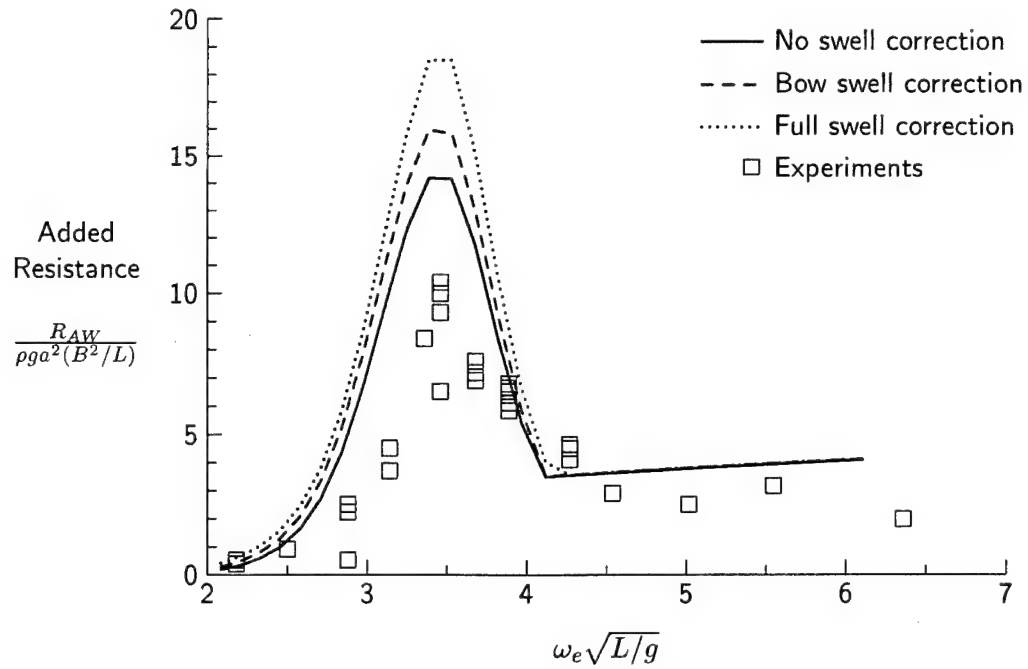


Figure 34: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.70$, $Fn = 0.222$

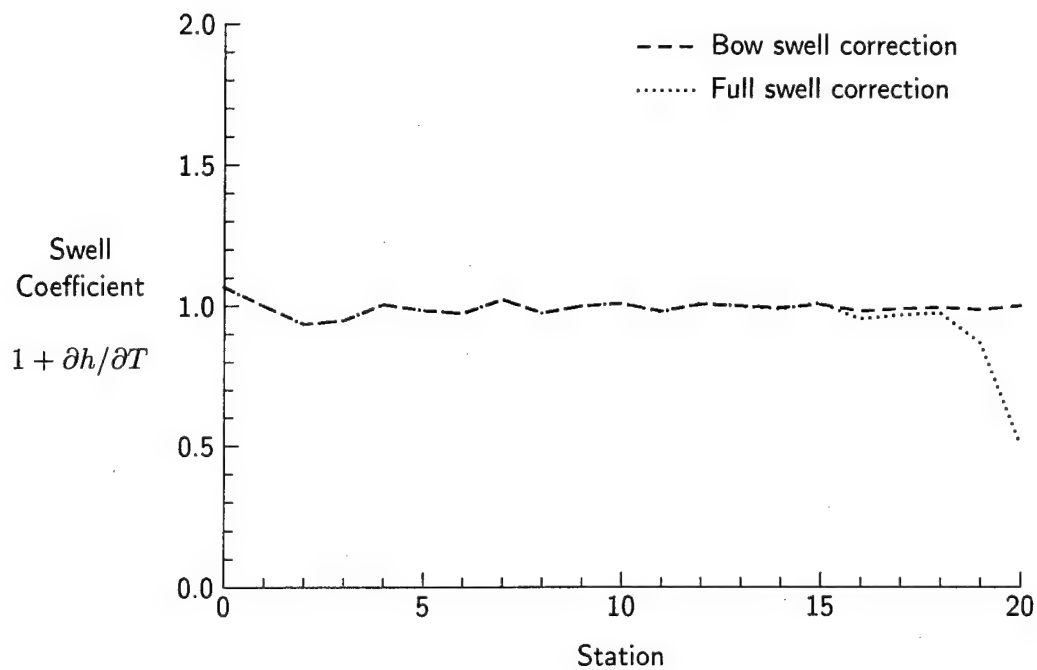


Figure 35: Swell-up Correction Factors for Series 60, $C_B = 0.80$, $Fn = 0.147$

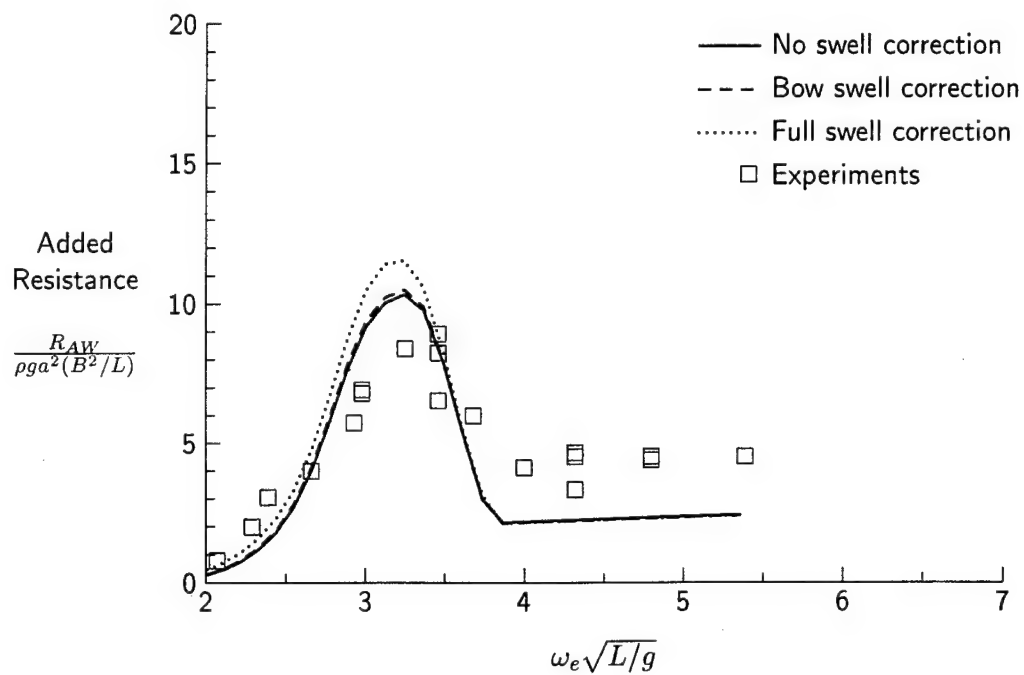


Figure 36: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.80$, $Fn = 0.147$

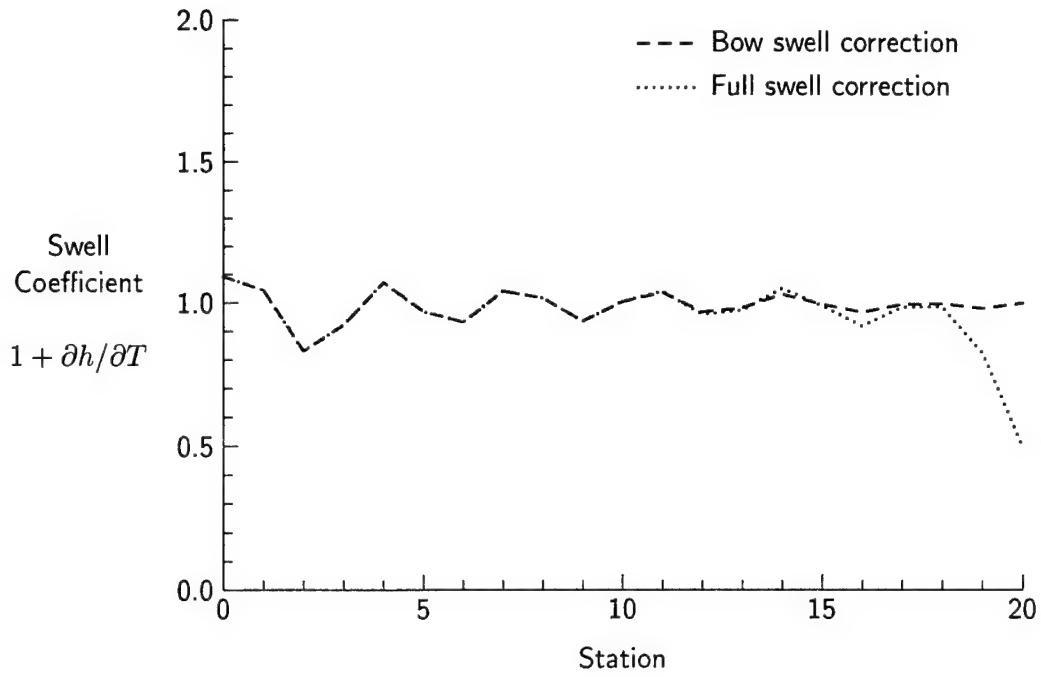


Figure 37: Swell-up Correction Factors for Series 60, $C_B = 0.80$, $Fn = 0.165$

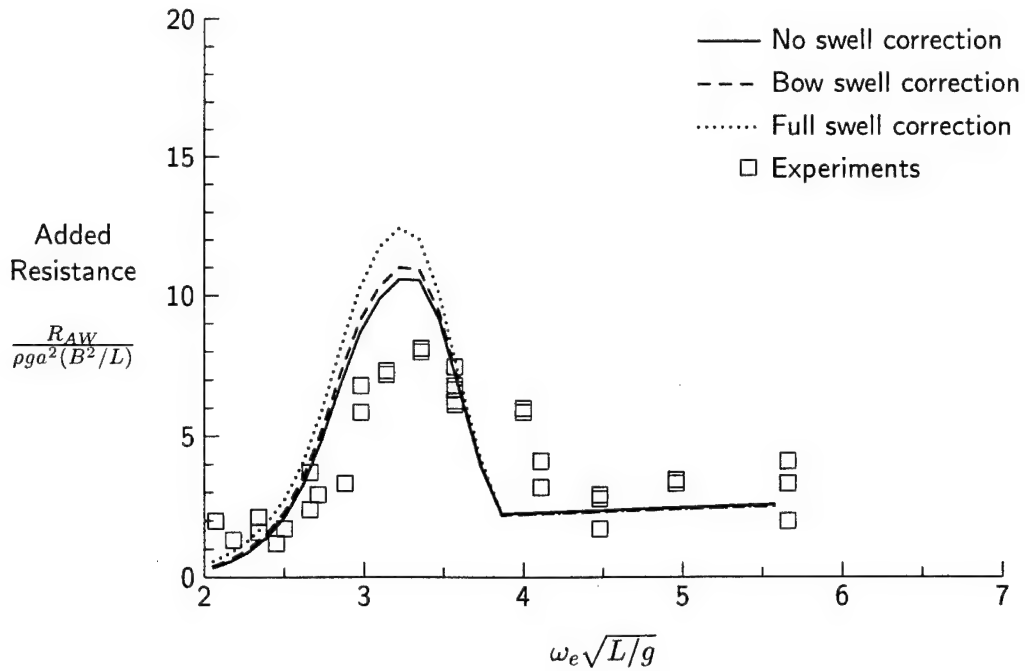


Figure 38: Influence of Swell-up Correction on Added Resistance in Head Seas for Series 60, $C_B = 0.80$, $Fn = 0.165$

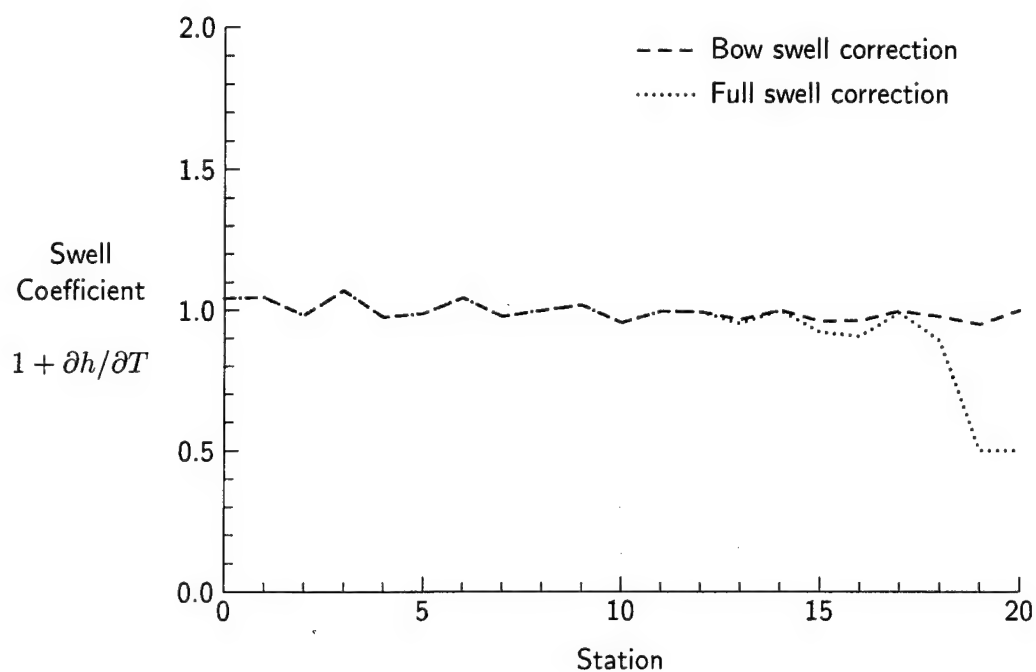


Figure 39: Swell-up Correction Factors for *FFG 7*, $Fn = 0.15$

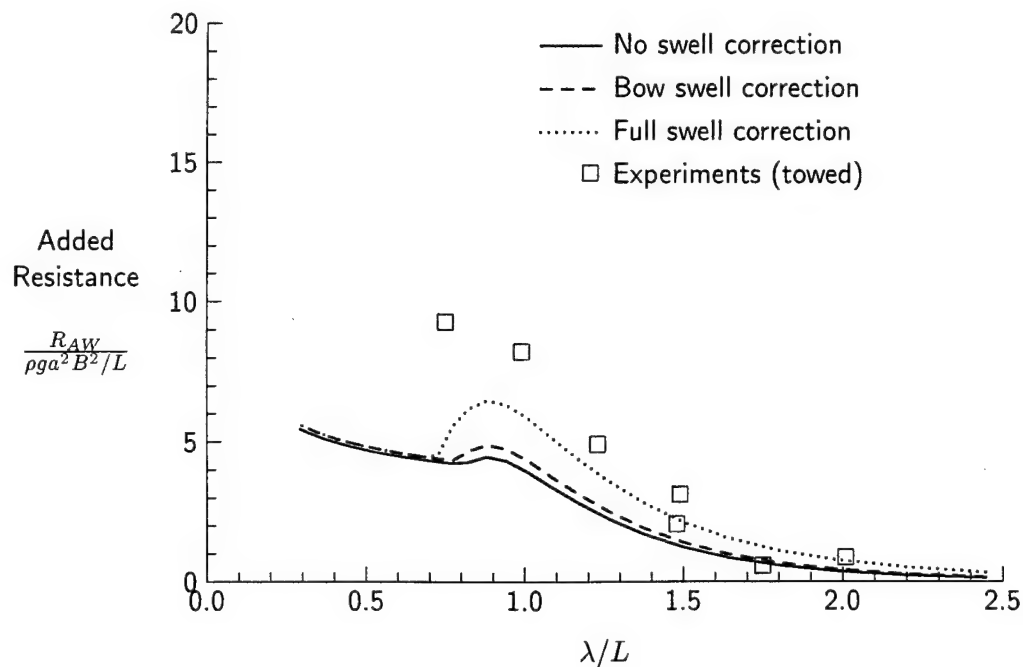


Figure 40: Influence of Swell-up Correction on Added Resistance in Head Seas for *FFG 7*, $Fn = 0.15$

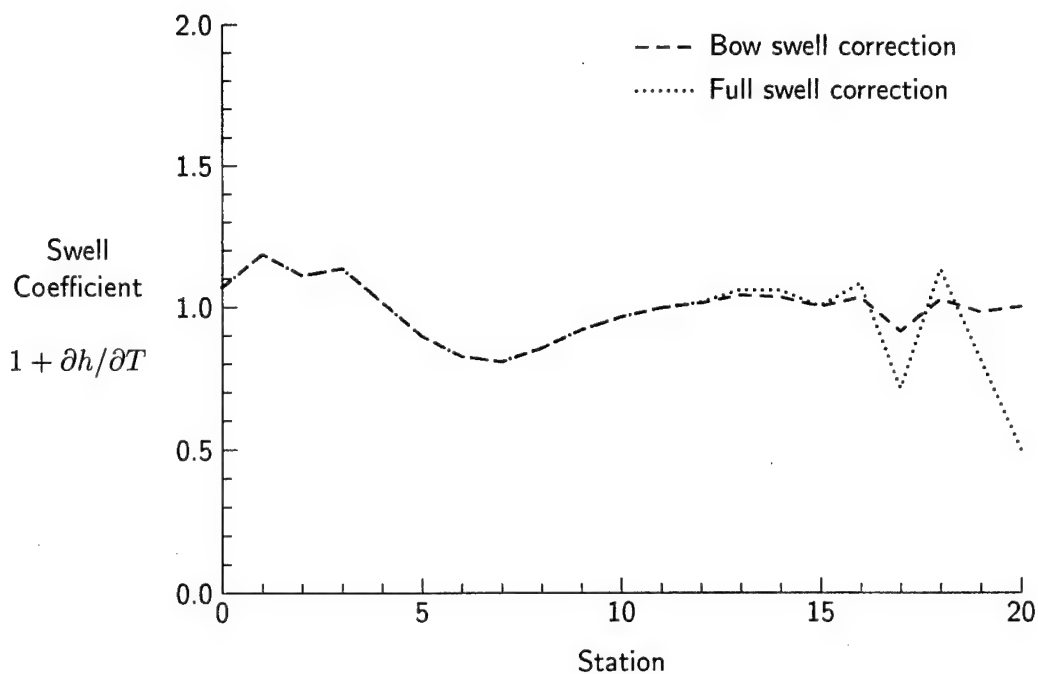


Figure 41: Swell-up Correction Factors for *FFG 7*, $Fn = 0.30$

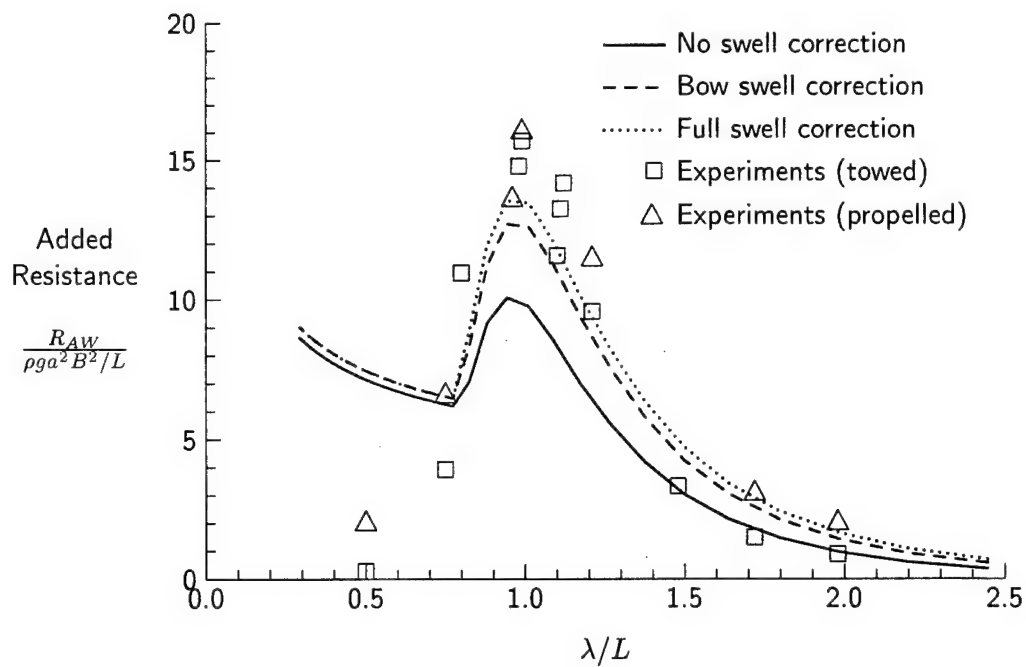


Figure 42: Influence of Swell-up Correction on Added Resistance in Head Seas for *FFG 7*, $Fn = 0.30$

7 Conclusions

SHIPMO7 includes a near-field method for computing added resistance in waves. This method uses approximations based on short and long wavelengths to obtain added resistance across the entire wavelength range. It provides fair agreement with experimental results for Series 60 models in head seas and for the *FFG 7* in head and oblique seas. Unlike some other methods, the present method does not incorrectly predict large negative values of added resistance for the *FFG 7* in following seas.

The inclusion of swell-up correction due to ship forward speed appears to improve added resistance predictions in head seas for the *FFG 7*, which has a fine hull form. For the Series 60 ships, which have fuller hull forms, inclusion of swell-up correction leads to poorer agreement with experiments. For a transom stern ship, the SHIPMO7 option for bow swell-up correction should be applied rather than full swell-up correction.

Based on theoretical considerations, a three-dimensional ship motion code such as SMCA4 should be able to give better added resistance predictions than the strip theory of SHIPMO7. A validation study comparing the results of SMCA4 and other available three-dimensional codes with the present strip theory implementation would be worthwhile.

References

- [1] O.M. Faltinsen, K.J. Minsaas, N. Liapis, and S.O. Skjoldal, "Prediction of Resistance and Propulsion of a Ship in a Seaway," in *Thirteenth Symposium on Naval Hydrodynamics* (Tokyo, 1980), pp. 505-529.
- [2] K.A. McTaggart, "SHIPMO7: An Updated Strip Theory Program for Predicting Ship Motions and Sea Loads in Waves," DREA Technical Memorandum 96/243, 1996.
- [3] R.T. Schmitke and B.W. Whitten, "SHIPMO - A FORTRAN Program to Predict Ship Motions in Waves," DREA Technical Memorandum 81/C, October 1981.
- [4] T.H. Havelock, "Drifting Force on a Ship Among Waves," *Philosophical Magazine* **33**, 267-475 (1942).
- [5] H. Maruo, "The Excess Resistance of a Ship in Rough Seas," *International Shipbuilding Progress* **4**, 337-345 (1957).
- [6] J. Gerritsma and W. Beukelman, "Analysis of the Resistance Increase in Waves of a Fast Cargo Ship," *International Shipbuilding Progress* **19**(217), 285-293 (1972).
- [7] N. Salvesen, "Added Resistance of Ships in Waves," *Journal of Hydronautics* **12**(1), 24-34 (1978).
- [8] N. Salvesen, "Second-order Steady-state Forces and Moments on Surface Ships in Oblique Regular Waves," in *International Symposium on the Dynamics of Marine Vehicles and Structures in Waves* (London, April 1974), pp. 212-226.
- [9] M.-C. Fang, "Second-Order Steady Forces on a Ship Advancing in Waves," *International Shipbuilding Progress* **38**(413), 73-93 (1991).
- [10] W.-C. Lin and A.M. Reed, "The Second Order Steady Force and Moment on a Ship Moving in an Oblique Seaway," in *Tenth Symposium on Naval Hydrodynamics* (London, 1976), pp. 333-351.
- [11] G.E. Hearn, K.C. Tong, and S.M. Lau, "Hydrodynamic Models and their Influence on Added Resistance Predictions," in *PRADS '87 - The Third International Symposium on Practical Design of Ships and Mobile Units* (Trondheim, Norway, June 1987), Vol. 3, pp. 302-316.
- [12] C.C. Hsiung and Z.J. Huang, "Final Report: The Frequency-Domain Prediction of Added Resistance of Ships in Waves Using a Near-Field, 3-Dimensional Flow Method," DREA Contractor Report CR/95/484, October 1995.
- [13] J. Strom-Tejsen, H.Y.H. Yeh, and D.D. Moran, "Added Resistance in Waves," *Transactions, Society of Naval Architects and Marine Engineers* **81**, 109-143 (1973).
- [14] J.F. O'Dea and Y.H. Kim, "Added Resistance and Power of a Frigate in Regular Waves," Report DTNSRDC/SPD-0964-02, DTNSRDC, September 1981.

- [15] K.A. McTaggart, "Implementation and Assessment of Added Resistance Predictions using Program SHIPMO," DREA Technical Memorandum 92/217, September 1992.
- [16] C.C. Hsiung and Z.J. Huang, "User's Guide for SMCA4, A Computer Program for Ship Motion, Sea Loads, and Added Wave Resistance Prediction," DREA Contractor Report CR/95/485, October 1995.
- [17] J.J. Blok and J. Huisman, "Relative Motions and Swell-Up for a Frigate Bow," *Transactions, Royal Institution of Naval Architects* **126**, 227-244 (1984).
- [18] F.H. Todd, "Some Further Experiments on Single-Screw Merchant Ship Forms - Series 60," *Transactions, Society of Naval Architects and Marine Engineers* **61**, 516-589 (1953).
- [19] A.E. Baitis, W.G. Meyers, and T.R. Applebee, "A Non-aviation Ship Motion Data Base for the DD 963, CG 26, FF 1052, FFG 7 and the FF 1040 Ship Classes," Report SPD-738-01, David W. Taylor Naval Ship Research and Development Center, December 1976.

UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA <small>(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)</small>		
1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence Research Establishment Atlantic P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7	2. SECURITY CLASSIFICATION <small>(Overall security of the document including special warning terms if applicable.)</small> <div style="text-align: center; font-size: 1.2em; font-weight: bold;">UNCLASSIFIED</div>	
3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title.) <div style="text-align: center; font-size: 1.1em;">Added Resistance Prediction in SHIPMO7 Using a Near-Field Method</div>		
4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.) <div style="text-align: center; font-size: 1.1em;">MCTAGGART, Kevin A.</div>		
5. DATE OF PUBLICATION (Month and year of publication of document.) <div style="text-align: center; font-size: 1.1em;">January 1997</div>	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.) <div style="text-align: center; font-size: 1.1em;">38</div>	6b. NO. OF REFS. (Total cited in document.) <div style="text-align: center; font-size: 1.1em;">19</div>
6. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.) <div style="text-align: center; font-size: 1.1em;">DREA Technical Memorandum</div>		
8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development. include the address.) Defence Research Establishment Atlantic P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7		
9a. PROJECT OR GRANT NUMBER (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) <div style="text-align: center; font-size: 1.1em;">1.g.b.</div>	9b. CONTRACT NUMBER (If appropriate, the applicable number under which the document was written.) 	
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) <div style="text-align: center; font-size: 1.1em;">DREA Technical Memorandum 97/207</div>	10b. OTHER DOCUMENT NUMBERS (Any other numbers which may be assigned this document either by the originator or by the sponsor.) 	
11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification) <div style="font-family: monospace;"> <input checked="" type="checkbox"/> Unlimited distribution <input type="checkbox"/> Distribution limited to defence departments and defence contractors; further distribution only as approved <input type="checkbox"/> Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved <input type="checkbox"/> Distribution limited to government departments and agencies; further distribution only as approved <input type="checkbox"/> Distribution limited to defence departments; further distribution only as approved <input type="checkbox"/> Other (please specify): </div>		
12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.) <div style="text-align: center; font-size: 1.1em;">Unlimited</div>		

UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM

DCDO3 2/06/87

13. **ABSTRACT** (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

This technical memorandum discusses the implementation of a near-field method for prediction of added resistance in the strip theory program SHIPMO7. Comparisons with experimental data for Series 60 hull forms and a frigate indicate accuracy similar to other methods, including three-dimensional codes. Advantages of the current method include computational efficiency, robustness, and reasonable values for added resistance in following seas. Inclusion of the SHIPMO7 dynamic swell-up option improves accuracy of added resistance predictions for the frigate but degrades accuracy for the Series 60 hull forms.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

added resistance
drift forces
seakeeping
ship motions
strip theory
surge
sway
roll
pitch
yaw